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APPLIED RESEARCH AND DEVELOPMENT WORK ON FAMILIES OF BRAZED AND WELDED FITTINGS FOR ROCKET PROPULSION FLUID SYSTEMS

FINAL REPORT

TECHNICAL DOCUMENTARY REPORT NO. RPL-TDR-64-24
FEBRUARY 1964

Air Force Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards, California

Project No. 6753, Task No. 675304

(Prepared under Contract No. AF 04(611)-8177 by the
Los Angeles Division, North American Aviation, Inc.
Los Angeles, California 90009
M. H. Weisman, P. A. Beeson, G. Martin, W. D. Padian, C. J. Muser,
J. Melill, S. Salmassy, S. G. Smithhart, A. G. Dillingham, Jr.,
T. Fan, G. C. Sine, J. R. West and G. L. Ball, authors)

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FOREWORD

This Technical Documentary Report covers the work performed under U. S. Air Force Contract No. AF 04(611)-8177, and is the Final Report on the contract. The contract work included the selection of materials for tubing and tube fittings for use in rocket propulsion fluid systems, the development of braze and weld procedures and equipment for joining these materials, the design of lightweight brazed and welded fittings, the design and installation of facilities for qualification testing of the fittings, the manufacture and qualification testing of selected fittings in selected sizes and materials, and the preparation of drawings, descriptions, and test requirements for the fittings and joining tooling to assist the Air Force in the preparation of specifications for the procurement of suitable fittings and joining equipment.

This contract is sponsored by the Research and Technology Division, Air Force Systems Command, U. S. Air Force, Edwards, California. It is established under Air Force Program Structure No. 750G, AFSC Project No. 6753, AFSC Task No. 675304. Mr. Roy A. Silver of the Air Force Rocket Propulsion Laboratory, Liquid Rocket Division, Propulsion Sub-Systems Branch, is the USAF Project Engineer.

This program was conducted in the Research Laboratories of the Los Angeles Division, North American Aviation, Inc., International Airport, Los Angeles, California 90009. Mr. G. A. Fairbairn, Group Leader of the Metallic Materials Laboratory, was the Program Manager, and Mr. M. H. Weisman of the Metallic Materials Laboratory was the Project Engineer for the Contractor. The following persons participated in the program work in the areas noted and in the preparation of the Final Report.

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ABSTRACT

The development of lightweight designs of brazed and welded fittings, the design and manufacture of prototype joining tooling required to fabricate the fittings, and the manufacture and qualification testing of fittings in selected sizes and materials for use in rocket propulsion fluid systems are described in this report. Recommendations are presented for materials for use as tubing and fittings for such systems. These material recommendations are based on a literature survey on the compatability of candidate materials with rocket propellant fluids, and on the consideration of the effects of the fitting joining processes on the materials. Other parameters that could significantly affect the fitting classification and design, such as material cost, availability, and braze alloy shear strength have been investigated. Joining procedures and joint designs have been developed and qualification tests conducted for induction brazed and for machine TIG welded families of joints in AISI Type 347 and AM 350 stainless steel and Rene' 41 alloy tubing, and for machine TIG welded joints in 6061-T6 aluminum alloy tubing. A total of 76 tube and tube joint specimens were tested for leakage, proof pressure, burst pressure, temperature shock, pressure impulse cycling, stress reversal bending, and vibration. All the test joints successfully completed the proof pressure, leakage, burst pressure, temperature shock and pressure impluse requirements. There were no failures of the fitting sleeves of any of the brazed or welded joint test specimens. The test joint failures which did occur in the stress reversal bending tests and in the vibration tests originated in the specimen tubing; in the heat affected zone adjacent to the weld bead of the weld specimens, and at the edge of the braze alloy bond on the brazed joint specimens. Careful examination of the failed specimens did not reveal any defects, either in the joint or in the specimen materials, which would cause premature failure. Analysis of the test conditions indicated the specimen life was quite reasonable, considering the very high bending stress level which was specified for the stress reversal bending and vibration tests. Therefore, based on the overall performance in the Qualification Test Program, the joint designs and joining procedures developed under this program are considered to be acceptable for use in rocket propulsion fluid systems. Drawings, descriptions, and test requirements for the fittings and joining tooling have been prepared in a manner to assist the Air Force in the preparation of specifications for the procurement of suitable fittings and joining equipment.

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1. INTRODUCTION

The systems and components of rocket propulsion vehicles must function under severe environmental and operational conditions. Rocket propulsion fluid systems, in particular, are subjected to extremes of temperature, pressure, vibration, and the effects of radiation encountered in space. The use of new and exotic propellants and other fluids has produced new problems of chemical activity and material compatibility.

The conventional aircraft-type fitting designs currently being used for tubing connections in rocket propulsion fluid systems have proven inadequate because of problems of corrosion, leakage, and fatigue failure. New advanced tube joining concepts are required which will provide zero leakage and light weight with high operational reliability.

Techniques for making "in-place" tubing connections by brazing and by welding had been developed by the Los Angeles Division of North American Aviation, Inc., for use on the X-15 and XB-70 air vehicles. These techniques were considered to be feasible for further development for joining tubing for advanced rocket propulsion fluid systems.

The purpose of this program was to develop, design, fabricate, and qualify light weight brazed and welded fittings for service with rocket propulsion fluid systems. This program was conducted in three phases:
Phase I - Material Selection, Process Development, and Preliminary Design;
Phase II - Design and Manufacture of Joining Tools and Fittings, and Qualification Testing of Fittings;
Phase III - Final Design of Fittings and Joining Tooling, Preparation of Specifications, and Reporting.

Phase I consisted of a literature survey of the compatibility of typical storable and cryogenic propellants and pressurizing gases with the candidate tubing and fitting materials and with the brazing alloys under consideration. Fitting materials and brazing alloys were selected. Brazing and welding process parameters for these materials were investigated and suitable joining procedures were developed. A stress analysis of the proposed fitting designs was prepared. A detailed plan for the qualification testing of the fittings was prepared and was approved by the USAF Project Engineer. The facilities required for the qualification tests were designed and fabrication and installation of these facilities was initiated.

In Phase II the installation and check out of the qualification test facilities were completed. Prototype joining tooling required to fabricate the test fitting assemblies was designed and manufactured. Designs for the test fitting assemblies were prepared and the fittings and other components for the qualification test specimens were made. The final parameters for joining the test materials were determined, and the qualification test specimens were assembled by brazing and by welding. The qualification test program was conducted and, on the basis of the overall results, the joint designs and joining procedures developed under this program were considered to be acceptable for use in rocket propulsion fluid systems.

Phase III of the program consisted of the final design of the fittings and joining tooling, the preparation of the Final Report covering the entire program, and the preparation of drawings, specifications, and test requirements for the fittings and joining tooling in a manner to assist the Air Force in the preparation of specifications for the procurement of suitable fittings and joining equipment.

The program has been completed and the work conducted and the results which have been obtained are presented in this report.

2. MATERIAL SELECTION

2.0 GENERAL CONSIDERATIONS

Rocket propulsion fluid system tubing and fittings are required to meet service temperatures and pressure schedules such as those shown in Table I, and to be compatible with the system fluids and operational environment. An added requirement which must be fully considered under this program is the effects which the braze or weld joining processes may have on the tubing and fitting materials and their resultant suitability for use in particular systems. The primary factors which must be considered in material selection are:

(1) Chemical compatibility with the system fluids listed in Table II.

(2) A high strength/weight ratio at the maximum service temperature for the system as shown in Table I.

(3) Ability to be satisfactorily joined by brazing and/or welding processes being developed under this program.

(4) Commercial availability of the material in suitable forms and shapes.

Additional factors which are also important are:

(5) Machinability.

(6) Cost.

(7) Accelerated fatigue damage or embrittlement due to service conditions, such as temperature shock, vibration, etc.

(8) Sensitivity to radiation or space environment.

The welding and brazing properties of the materials will be discussed in the appropriate sections later in this report. The other factors listed above will be discussed in the following paragraphs.

The mechanical, physical, and chemical properties important in selecting materials for rocket fluid systems, in many cases, vary as a function of the operating temperature range of the system. The lower temperature range of the service environment for the systems considered under this program is -423 F, the temperature of liquid hydrogen, for the propellant system, and -320 F, the temperature of liquid nitrogen, for the pneumatic systems. Testing under this program will be conducted at temperatures only as low as -320 F for both types of systems. The upper temperature limit for the propellant system and one type pneumatic system are 200 F, for the second type pneumatic system 600 F, and 1500 F for the third type pneumatic system. The fitting classification service environments and the rocket system fluids to be considered under this program are presented in Tables I and II, respectively.

TABLE I

FITTING CLASSIFICATION

SERVICE	SYSTEM OPERATING PRESSURE RANGE	SYSTEM OPERATING TEMPERATURE RANGE	SYSTEM TUBING DIMENSIONAL RANGE
Propellant	0 to 2500 psig	-423 F to 200 F	1 to 2 inches in 1/4 inch increments 2 to 3 inches in 1/2 inch increments 3 to 5 inches in 1 inch increments 6 to 16 inches in 2 inch increments
Pneumatic	0 to 3000 psig	-320 F to 200 F	1/8 to 1/4 inch in 1/16 inch increments
	0 to 1000 psig	-320 F to 200 F	5/16 to 1 inch in 1/16 inch increments
	0 to 10,000 psig	-320 F to 600 F	1/8 to 1 inch in 1/16 inch increments
	0 to 4000 psig	-320 F to 1500 F	

TABLE II

ROCKET SYSTEM FLUIDS
TO BE CONSIDERED FOR USE WITH
LIGHTWEIGHT BRAZED AND WELDED FITTINGS

Fitting Service Classification	Fluid Type Classification	Description of Rocket System Fluid
Propellant	Storable Propellants	(a) UDMH-Hydrazine Blends (0 to 100 percent N_2H_4) (b) Hydrogen Peroxide (c) Nitrogen Tetroxide (d) Chlorine Trifluoride (e) Pentaborane (f) Red Fuming Nitric Acid (g) White Fuming Nitric Acid (h) RP-1 (i) MMH (j) N_2F_4
	Cryogenic Propellants	(k) Liquid Oxygen (l) Liquid Hydrogen (m) Liquid Fluorine (n) OF_2 (o) ClO_3F
Pneumatic	Ambient Temperature Gases	(p) Gaseous Oxygen (q) Gaseous Hydrogen (r) Gaseous Nitrogen (s) Gaseous Helium
	Elevated Temperature Gases	(t) High Temperature Hydrogen Gas (u) High Temperature Helium Gas (v) High Temperature Combustion Products Associated with solid and Liquid Propellants Reactions (Flow Rates of the order of two (2) pounds per second)

2.1 CHEMICAL COMPATIBILITY

The primary requirement of a material to be used for tubing or fittings in rocket propulsion fluid systems is that it be chemically compatible with the fluids to be contained. This compatibility must be mutual; that is, the fluid must not attack the system material and cause a reduction in the material strength, nor must the system material itself cause any change in the composition of the fluid, either by direct or catalytic action. Chemical attack by the fluid on the system material generally implies a surface corrosion action which reduces the effective thickness of the tubing or fitting and thus reduces its strength. Other factors to be considered are stress corrosion attack and the formation of loose corrosion products or of sludge which may block passages or interfere with the operation of valves.

The braze and weld processes for joining tubing and fittings which are being developed under this program introduce factors which can considerably complicate the compatibility problem. The usual dissimilarity which exists between a brazing alloy and the materials being joined cause brazed joints to have an inherent chemical inhomogeneity, the effect of which must be evaluated. The problem of material dissimilarity in welded joints can be minimized by proper selection of the tubing, fitting, and weld filler materials. Some chemical compatibility difficulties may still arise in welded joints, however, due to such causes as differences in the metallurgical structure or heat treat condition of the several joint materials.

One of the principal problems in assessing the compatibility of the system materials with the fluids contained is the general scarcity of comprehensive and reliable data. Complete information on the materials and test conditions are available in only a few cases. Many compatibility data which appear in the literature do not specify the state of heat treatment of the test material. Few, if any, tests seem to have been conducted on stressed materials exposed in the fluids listed in Table II for consideration under this program.

A review of the technical literature was conducted to gather information on the chemical compatibility and other properties of candidate tubing and fitting materials with the rocket propulsion system fluids considered in this program. The most valuable literature sources are listed in the REFERENCES section at the end of this report and are also referred to in specific areas below. Additional data were obtained from tests which had previously been conducted by the several divisions of North American Aviation, Inc. This information on the chemical compatibility of a number of tubing and fitting materials with the propulsion system fluids and pressurizing gases considered in this program is presented in summary form in Table III. In addition to this information, the following comments are relevant to the various groups of fluids and gases.

TABLE III. RECOMMENDATIONS CONCERNI
CANDIDATE MATERIALS WITH

MATERIAL TYPE	N_2H_4	UDMH-N_2H_4 BLEND(3)	UDMH and MMH	N_2O_4	WFNA and RFNA	H_2O_2	ClF_3 (4)	OF_2 (4)	ClO_3F (4)	F_2 (4)	N_2F_4
STAINLESS STEELS											
304L	A(1)	B(1)			B(2)					B(10)	
316	C(1)	C(1)									
321	B(1)	B(1)	B(1)	A(2)	A(2)	B(2)	B	B	B		A
347										B(6)(10)	
A-286	C(1)	C(1)			B(2)						
17-7PH	B(1)	B(1)									
350	C(1)(5)	C(1)(5)		B(2)			C			D	D
355			C(1)(5)		C(2)(5)	C(2)(6)	C(5)	C(5)	C(5)		
HEAT RESISTING ALLOYS											
Monel	D	D	D	D	D			B(11)	B(11)		A
K-Monel								A			
Inconel	A(1)							B(11)			
Inconel X	B(1)					D	A		A	A(10)	---
Inconel 718	B(1)	B(1)	A	A(1)	B(2)			A			
Rene' 41	A(1)										
Hastelloy C	D	D	C	B(1)				A(7)	B(7)		
ALUMINUM ALLOYS											
EC						A(2)(9)					
1100	A(1)										
3003	B(1)	B(1)	B	A(1)(9)	A(2)(9)	B(2)(9)	B	B	B(1)	A(10)	---
6061	A(1)										
2024	D	D	C	D	D	D		B(11)			
MISCELLANEOUS METALS											
Tantalum	A(1)			A	A(2)	A(2)	A	A(11)	A(11)	A(10)	A
Titanium		A	A	B(5)			D	D	D	D	
Nickel	C(1)						A(3)				D
Copper	D	D	D	D			B(2)	A(11)	A(11)	A(10)	A
Magnesium					D	D		B(2)	B(2)	B(2)(10)	
Gold	-	A	A	B			B	B	B	B(8)(10)	-
Silver	D	B	B	D			D	D	D	D	D

LE III. RECOMMENDATIONS CONCERNING CHEMICAL COMPATIBILITY OF CANDIDATE MATERIALS WITH ROCKET PROPELLANT FLUIDS.

O_2	ClF_3 (4)[3]	OF_2 (4)	ClO_3F (4)	F_2 (4)	N_2F_4	RP-1
	B	B	B	B(10)	A	A
				B(6)(10)		
	C			D	D	
6)	C(5)	C(5)	C(5)			B(10)
	A	B(11)	B(11)	A(1C)	A	C
		A	A		---	A
		B(11)				
		A				
		A(7)	B(7)			
9)						
9)	B	B	B(1)	A(10)	---	A
		B(11)				C
	A	A(11)	A(11)	A(10)	A	A
	D	D	D	D	D	
	A(3)	A(11)	A(11)	A(10)		
	B(2)				A	D
		B(2)	B(2)	B(2)(10)	-	A
	B	B	B	B(8)(10)		
	D	D	D	D	D	

EXPLANATION OF SYMBOLS AND NOTATIONS:

A Material suitable for unlimited service involving long-term storage of propellant.

B Material suitable for storage of propellant under limited conditions, and for short-term contact prior to storage of propellant.

C Material suitable only for short-term contact prior to use of propellant.

D Material not suitable for use with propellant.

(1) Service limited to 160 F maximum and with dry propellant.
(2) Materials must be suitably passivated prior to use with propellant.
(3) 50/50 blend by weight of UDMH and N_2H_4.
(4) Use of all metals is contingent on suitable stabilization. Extended service of stainless steels in these propellants may result in heavy deposits of fluorides. Systems utilizing stainless steel should be flushed after each use at high temperature to remove fluoride deposits.
(5) May be susceptible to chemical attack by propellant.
(6) May be susceptible to stress corrosion by propellant.
(7) Service limited to 160 F maximum.
(8) Attacked by dry fluorine at temperatures above 590 F.
(9) Suitable only for short-time use in systems where metals other than aluminum alloys are also in contact with propellant because of resulting preferential chemical attack on aluminum alloys by propellant.
(10) Suitable for use with dry propellant only.
(11) Service limited to 212 F maximum.

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Hydrazine and Derivatives

Hydrazine (N_2H_4), hydrazine derivatives such as UDMH (unsymmetrical dimethylhydrazine) and MMH (monomethyl hydrazine), and mixtures of these fluids exhibit only minor differences in their compatibility with candidate tubing and fitting materials. In the dry state and at temperatures below 160 F these propellants are compatible with a variety of materials; but when moist, hydrazine tends to attack the stainless steels, References (4), (5) and (6).

Inconel is the tubing or fitting material which is most compatible for use with hydrazine and its derivatives. Tantalum, Rene' 41, aluminum and some aluminum alloys are also satisfactory for use with hydrazine and hydrazine derivatives.

Welding has been found to be a satisfactory method of joining the above materials for service with hydrazine and hydrazine derivatives. The only information available on the compatibility of brazed joints for use with hydrazine and its derivatives is for silver brazed joints with brazing alloys such as Easyflow 45. The data indicate that silver brazed joints are compatible for use with hydrazine and its derivatives.

Fuming Nitric Acids

Only a few materials are satisfactory for use as tubing and fittings with the fuming nitric acids. As shown in Table III, these materials include tantalum and several of the stainless steels. Aluminum and several of the aluminum alloys are suitable for use with the fuming nitric acids if the acid will not also contact other metallic materials. Systems in which other metals as well as aluminum alloys will be in contact with fuming nitric acids are suitable only for short time use. In such systems the aluminum and aluminum alloy components are subject to preferential galvanic attack by the propellant. See References (4) and (6).

Titanium and titanium alloys should never be used for systems to contain fuming nitric acids. Under certain conditions the fuming nitric acids react with titanium and titanium containing metals to form compounds which are extremely shock sensitive. Violent reactions may then occur, particularly when such compounds are in contact with the fuming nitric acids, References (4) and (7).

Welding is indicated to be the preferred method of joining materials for service in fuming nitric acid systems. The compatibility and corrosion resistance of brazed joints for fuming nitric acid service could not be established on the basis of the data available, although noble metal brazing alloys such as gold-palladium appear to be promising

The use of stainless steels for components of fuming nitric acid systems which are assembled by welding or which may be exposed at times to temperatures above 700-800 F involves certain problems. Even with the stainless steel alloys which are listed in Table III as compatible with fuming nitric acids, care must be taken to eliminate the effects of any

carbide precipitation reactions which may result or to avoid such reactions entirely. Such adverse reactions in stainless steels are generally avoided by use of the stabilized AISI 321 and AISI 347 alloy grades. Weldments of these alloys are normally satisfactory for use in the as-welded condition. However, unless properly heat treated by solution annealing after welding, the weld areas of even these stabilized stainless steels are susceptible to stress corrosion by the fuming nitric acids. Adverse carbide precipitation effects may be minimized by the use of extra-low carbon stainless steels, which should therefore be specified for service with fuming nitric acids for parts which are to be welded.

Nitrogen Tetroxide

The compatibility of tubing and fitting materials with nitrogen tetroxide (N_2O_4) is generally considered to be similar to the compatibility of the materials with the fuming nitric acids. The specific recommendations shown in Table III were prepared on the basis of the survey of the technical literature. In the interpretation of these recommendations it should be noted that nitrogen tetroxide, in the presence of free water, will ionize in such a manner that it may behave the same as a fuming nitric acid. Because of this possibility the literature recommends that when certain materials, such as titanium and its alloys, are considered for nitrogen tetroxide service, that tests be made of the proposed application in the configuration that the materials will be used and under the conditions to which they will be subjected during the anticipated service lifetime. See References (4), (6), (8), (9), (10) and (11).

Fluorine and Fluorine Compounds

Fluorine and fluorine compounds such as oxygen difluoride (OF_2), perchloryl fluoride (ClO_3F), chlorine trifluoride (ClF_3), and nitrogen fluoride (N_2F_4) are considered together. Most metals and alloys with a high oxidation resistance are suitable for use with these propellant fluids. Monel and the stainless steels, in general, are the preferred materials. However, the AISI 347 stainless steel grade has been reported to be susceptible to stress corrosion by liquid fluorine, References (4) and (12). These materials are usually subjected to a passivating treatment prior to use with these fluids. See References (4), (6) and (12). This treatment produces a passive fluoride film on the metal surfaces which then protects the surfaces from further attack by the fluoride propellant fluid.

Extended service of stainless steels in these propellants may result in heavy deposits of fluorides on the metal surfaces, Reference (13). No data are available on the effects of fast moving streams of propellants which might disturb or erode the passivated protective fluoride films and thus increase the corrosion rate.

Striking, repeated bending, flexing, or excessive vibration of fluoride propellant piping or tankage should be avoided. Such mechanical actions can result in flaking, cracking, or breaking of the protective fluoride film on the internal surfaces of the system. With certain of these propellants, such as chlorine trifluoride, this can result in a rupture of

the metal and a possibly violent reaction between the metal and the propellant. Flaking of the protective film can produce particles which may interfere with valve operation or block small tubing lines, References (4) and(14).

Welded joints are recommended to connect piping and tankage for handling these propellant fluids.

No data are available on the compatibility of nitrogen fluoride (N_2F_4) with metals. Tentative recommendations for N_2F_4 materials compatibility which are given in Table III were obtained from Reference (13).

Boranes

These propellants do not present a material compatibility problem. All commercial metals and alloys are suitable for use with the borane compounds. It is very important that systems containing the borane compounds be sound and leaktight because of the extreme toxicity of the borane compounds.

Hydrocarbon Fuels

No special corrosion problems are experienced with RP-1 or other hydrocarbon propellant fluids, although excessive moisture in the fluid may cause corrosion or rusting in materials subject to atmospheric corrosion. Such corrosion problems may be aggravated by galvanic couples produced by the presence of brazing alloys or combinations of dissimilar metals in a system.

Hydrogen Peroxide

The main problem connected with the selection of materials for fabrication of hydrogen peroxide (H_2O_2) fluid systems is not so much the attack of the fluid on the materials, but rather, the effect of many materials on the decomposition of the hydrogen peroxide, Reference (4).

High purity aluminum, the 5000 series of aluminum alloys, and tantalum appear to be the only materials which are fully satisfactory for extended storage of hydrogen peroxide. Under short-term contact conditions it becomes possible to use a wider variety of alloys including, principally, the AISI 300 series stainless steels without adverse service compatibility effects.

Experience with the hydrogen peroxide system on the X-15 rocket powered aircraft has shown that problems arise when aluminum tubing and fittings are used in connection with other materials, such as stainless steels. The electro-chemical problems which resulted were such that aluminum and aluminum alloys have been eliminated from the tubing and tankage systems for hydrogen peroxide on the X-15. Aluminum tubing, therefore, should be considered only for an all-aluminum structure, unless the aluminum materials can be electrically insulated from the other materials in the system.

Surface finish is a factor in determining compatibility of materials with hydrogen peroxide. The smoother the surface, the less is the chance of there being undesirable effects, such as liquid-phase decomposition of the hydrogen peroxide. Therefore, it is necessary to ensure that the joints present as little discontinuity as possible in hydrogen peroxide systems. See Reference (4).

Materials such as Hastelloy B and C, and 19-9DL stainless and heat resisting steel, may be used only for short-time contact with hydrogen peroxide. These materials may cause contamination of hydrogen peroxide solutions sufficient as to make them unfit for storage, Reference (4).

The following materials are considered unsuitable for any use with hydrogen peroxide solutions. In general, they may cause rapid decomposition of the hydrogen peroxide, are rapidly attacked, or form explosive mixtures with hydrogen peroxide. Such materials include copper and copper alloys, lead, the AISI 400 series stainless steels, magnesium, zinc, and gold and silver alloys, Reference (4).

Liquid Oxygen and Liquid Hydrogen

Materials selected for tubing systems and fittings for use with liquid oxygen or liquid hydrogen must have adequate strength and toughness at cryogenic temperatures. The strength of materials increases as the temperature decreases; but, generally, materials lose toughness and become brittle or notch sensitive at cryogenic temperatures. Toughness of the material at low temperatures, therefore, becomes the controlling factor. The AISI 300 series austenitic stainless steels, most aluminum alloys, nickel alloys, and superalloys are satisfactory.

Materials for use with liquid oxygen must not undergo self-propagating reactions with the liquid oxygen. Such materials must be tested for shock sensitivity under service conditions, particularly as regards reactions on freshly cut surfaces. Titanium and titanium alloys ignite with liquid oxygen. The reaction will propagate and completely consume the titanium, Reference (11). Therefore, titanium and titanium alloys cannot be used for liquid oxygen systems.

Hot Exhaust Gases

The principal material requirement for hot exhaust gas system use is good high temperature strength. Any chemical reactions are likely to be greatly accelerated at high temperature. Therefore, traces of propellants which may be present in the hot gas stream are likely to be more corrosive than under normal storage conditions. The interaction between combustion products and metals has been studied recently, and the first results are described in Reference (15). It is generally concluded from these initial studies that the interaction can be predicted from thermodynamic data, except where metallurgical diffusion reactions, such as the formation of carbides, occur.

Recommendations for Compatibility and Corrosion Testing

The lack of reliable information on the chemical compatibility of the candidate materials for tubing and fittings with the fluids used in rocket propulsion systems makes it highly desirable that these materials be tested under service environment type conditions prior to general use. At least one representative member of each of the various rocket propulsion system fluid types should be selected as the corrosive environment medium. The fluid types which are suggested for use in the tests include a hydrazine compound, hydrogen peroxide, a fluoride compound, and nitrogen tetroxide.

In order to obtain results which can be expected to represent those which may occur in service, the tests should include a stressing factor to determine the susceptibility of the material to stress corrosion, a joining factor, and a space service factor. The joining factor will indicate the effects of electro-chemical action or of changes in the metallurgical structure of the tubing and fitting materials due to the presence of a brazing alloy and any heat treatment changes caused by the braze or weld cycles. Space service factors are those which are likely to affect materials with a high vapor pressure, such as cadmium or silver, both commonly used in brazing alloys. These same factors can affect many other materials which may develop appreciable vapor pressures at high temperatures. Radiation effects such as may occur in materials subject to space environments are complex and depend greatly on the type of radiation encountered. Vehicles in space will be exposed to primary cosmic radiation, which consists primarily of protons but also includes particles of higher mass. No detrimental effects are anticipated from cosmic rays in the metallic materials being considered under this program. In the Van Allen radiation belts, vehicles will be exposed to mainly electrons of energy greater than 13 Mev and to protons whose energy ranges to 700 Mev, Reference (16).

The radiation flux in the Van Allen belts can range from 10 roentgens per hour to as high as 1000 roentgens per hour, depending on solar conditions, Reference (16). The radiation exposure of a satellite orbiting under these conditions in the Van Allen belts for a period of two years would range from approximately 10^7 to 10^9 ergs per gram of carbon equivalent. By way of comparison, metals used in nuclear reactors are exposed to fluxes 10^5 to 10^6 times as great.

Exposure to cosmic ray or Van Allen belt radiation conditions for as long as several years is not considered damaging to metals. Damaging effects are produced in metals by exposure to fast or thermal neutron radiation. Such radiation is generated in nuclear reactors, but is not considered to be a factor in the radiation existing in space or in the Van Allen belts. Therefore, no general radiation tests are suggested here. Such tests, if desired, should be planned to fit the conditions established when details of specific types of missions are specified.

Studies of corrosion and of vacuum or space environment effects can be carried out using a number of different types of standardized specimens. Results which are most representative of service will be obtained if the tests are carried out on stressed specimens, and on specimens which incorporate welded and/or brazed joints. Such specimens permit the simultaneous

evaluation of both the stress and the electro-chemical factors. A number of corrosion and stress corrosion tests of fairly standardized types in general use throughout industry are presented in Reference (17).

The Contractor has conducted stress corrosion tests for a number of years using an elastically flexed simple beam type test specimen. This specimen is normally used for testing sheet material, although the specimen can be machined from bar stock. By a choice of suitable dimensions for the specimen size and deflection, the stress in the specimen can be made such that the maximum bending stress in the bent strip specimen is equal to some particular desired value, such as a certain percentage of the yield strength of the material. Details of this specimen and the calculations required to select the specimen size and test stress level are presented in Appendix IV.

2.2 STRENGTH CONSIDERATIONS

General Strength Parameters

Following the determination of satisfactory compatibility with the rocket propulsion system fluids, the selected candidate materials are then further evaluated against the following strength requirements. The necessity to minimize the weight of rocket propulsion vehicles makes it extremely important to consider the strength-to-weight ratio of constructional materials. The term "strength," as used here implies the effective strength of the material under service conditions. As a first approximation, the 0.2 percent offset yield strength, as determined by a short-time test at the maximum service temperature, can be taken as a measure of the usable strength of the material, although the following factors must be taken into account.

(1) Instability of the metallurgical structure. This can lead to either progressive softening and loss of strength during high temperature service, or to hardening and possible embrittlement after a period of elevated temperature service.

(2) Embrittlement effects resulting from stress corrosion or similar phenomena.

(3) Fatigue failure in installations subject to repeated stress cycling or vibration.

(4) Fracture toughness; that is, the ability of a material to contain cracks or defects without suffering a significant loss of strength. This factor is considered less important than the other factors listed above so far as the selection of materials for tubing and fittings is concerned. This is because even small stable (non-progressing) cracks and similar defects which penetrate through the wall of a tube would disqualify the tube because of leakage or loss of system pressure.

(5) Creep strength for applications involving service at elevated temperature for significant periods of time.

The modulus of elasticity of materials is important because both structural stiffness and the strain resulting from bending or from internal pressure stress are a function of the modulus of elasticity. It is desirable to use a material with as high a modulus as possible in order to maximize the stiffness of the component and minimize the resulting strain.

Strength Properties of Tube and Fitting Materials

The chemical compositions of candidate materials for tubing and fittings are presented in Tables IV, V, and VI. Tensile ultimate and yield strengths, tensile modulus of elasticity, and coefficient of linear thermal expansion values versus temperature are presented in Table VII for the most applicable candidate materials. Note must be taken of the heat treatment or condition of the materials as listed in Table VII. Fully heat treated materials, of course, have a high strength. However, in the case of welded and/or brazed fittings it is usually not possible to heat treat the connection after joining when in-place joining procedures are used. It is necessary, therefore, to consider the minimum properties as exhibited by the material in the annealed or "as welded" condition when evaluating the strength of materials to be used for systems on which in-place joining procedures are to be used. Unfortunately, reliable data on annealed properties are not available for many materials as this information is not usually considered to be of structural significance. In the case of welded and brazed fittings, the annealed and "as welded" strength properties of materials are required to determine the reduction in strength across the joint which may have to be accepted. The information presented in Table VII are taken principally from Reference (18), the NAA Material Properties Data Manual, and also from supplier brochures, such as References (19) and (53), and NAA test results, References (21) through (27).

In addition to the short-time elevated temperature strength, there are other effects of service temperatures on material properties which must be considered. Service at high temperatures may produce creep effects. Service under cryogenic conditions may cause brittleness and low notch toughness, or notch sensitivity. The problem of low temperature brittleness can be reduced by the choice of metals and alloys having a predominantly face-centered cubic lattice structure. Such materials are the austenitic stainless steels, aluminum and its alloys, and some superalloys.

TABLE IV. COMPOSITION OF ALUMINUM ALLOYS

TYPE	COMPOSITION (Percent)								
	MANGANESE	COPPER	ZINC	IRON	SILICON	MAGNESIUM	CHROMIUM	TITANIUM	ALUMINUM
EC	0.01 max	0.10 max	0.10 max	0.50 max	0.15 max	0.01 max	0.01 max	(a)	99.45 min
1100	0.05 max	0.20 max	0.10 max	1.00 max		-	-	-	99.00 min
2014	0.40 to 1.2	3.9 to 5.0	0.25 max	1.00 max	0.5 to 1.2	0.2 to 0.8	0.10 max	0.15 max	Remainder
2024	0.30 to 0.9	3.8 to 4.9	0.10 max	0.50 max	0.50 max	1.2 to 1.8	0.10 max	-	Remainder
5052	0.10 max	0.10 max	0.10 max	0.45 max		2.2 to 2.8	0.15 to 0.35	-	Remainder
6061	0.15 max	0.15 to 0.40	0.25 max	0.70 max	0.4 to 0.8	0.8 to 1.2	0.15 to 0.35	0.15 max	Remainder
7075	0.30 max	1.2 to 2.0	5.1 to 6.1	0.70 max	0.50 max	2.1 to 2.9	0.18 to 0.40	0.20 max	Remainder
356	0.10 max	0.20 max	0.20 max	0.50 max	6.5 to 7.5	0.2 to 0.4	-	0.20 max	Remainder
Tens 50	0.10 max	0.20 max	0.20 max	0.50 max	7.8 to 8.6	0.4 to 0.55	(b)	0.1to 0.2	Remainder
4043	0.05 max	0.30 max	0.10 max	0.80 max	4.5 to 6.0	0.05 max	-	0.20 max	Remainder

Notes: (a) Contains Boron 0.01 to 0.06 percent which must exceed the Titanium plus Vanadium.

(b) Contains Beryllium 0.1 to 0.3 percent.

TABLE V. COMPOSITION OF STAINLESS STEELS

TYPE	COMPOSITION (Percent)							
	Carbon maximum	Manganese maximum	Silicon maximum	Chromium	Nickel	Molybdenum	Titanium	Other (a)
302	0.15	2.00	1.00	17.00 to 19.00	8.00 to 10.00	—	—	—
303	0.15	2.00	1.00	17.00 to 19.00	8.00 to 10.00	(b)	—	0.15 min S
304L	0.03	2.00	1.00	18.00 to 20.00	8.00 to 12.00	—	—	—
316	0.08	2.00	1.00	16.00 to 18.00	10.00 to 14.00	2.00 to 3.00	—	—
321	0.08	2.00	1.00	17.00 to 19.00	9.00 to 12.00	—	5 x C min	—
347	0.08	2.00	1.00	17.00 to 19.00	9.00 to 13.00	—	—	10 x C min Cb-Ta
A-286	0.08	1.00 to 2.00	0.4 to 1.0	13.50 to 16.00	24.00 to 27.00	1.00 to 1.50	1.90 to 2.35	0.35 max Al, 0.001 to 0.010 B, 0.10 to 0.50 V
350	0.08 to 0.12	0.50 to 1.25	0.50	16.00 to 17.00	4.00 to 5.00	2.50 to 3.25	—	0.07 to 0.13 N
355	0.10 to 0.15	0.50 to 1.25	0.50	15.00 to 16.00	4.00 to 5.00	2.50 to 3.25	—	0.07 to 0.13 N
17-4PH	0.07	1.00	1.00	15.50 to 17.50	3.00 to 5.00	—	—	3.00 to 5.00 Cu 0.15 to 0.45 Cb+Ta
17-7PH	0.09	1.00	1.00	16.00 to 18.00	6.50 to 7.75	—	—	0.75 to 1.50 Al
PH15-7Mo	0.09	1.00	1.00	14.00 to 16.00	6.50 to 7.75	2.00 to 3.00	—	0.75 to 1.50 Al

Notes: (a) Remainder is Iron.

(b) Molybdenum or Zirconium 0.60 maximum.

TABLE VI. COMPOSITION OF HEAT-RESISTING ALLOYS

TYPE	NOMINAL COMPOSITION (Percent)																
	C	Mn	Si	Cr	Ni	Co	Mo	Ti	Fe	Al	Cu	Cb	Ta	W	B	Zr	S
Monel	0.1	1.1	0.35	-	67.0	-	-	-	1.3	-	30.0	-	-	-	-	-	0.01
K-Monel	0.15	0.7	0.50	-	66.0	-	-	-	0.9	2.75	29.0	-	-	-	-	-	0.005
Inconel	0.04	0.35	0.20	15.0	78.0	-	-	-	7.0	-	-	-	-	-	-	-	-
Inconel X	0.04	0.70	0.30	15.0	73.0	-	-	2.5	7.0	0.9	-	1.0	-	-	-	-	-
Hastelloy C	0.10	0.8	0.7	16.0	Rem.	-	17.0	-	5.5	-	-	-	-	4.0	-	-	-
Waspaloy	0.05	0.8	0.7	19.0	Fem.	13.5	4.3	2.5	1.0	1.3	-	-	-	-	0.005	0.06	-
Rene' 41	0.10	-	-	19.0	Rem.	11.0	10.0	3.0	3.0	1.5	-	-	-	-	0.005	-	-
Inconel 718	0.04	0.3	0.5	19.0	Rem.	0.5	3.0	0.8	18.0	0.6	0.3	Cb+Ta=5.0		-	-	-	-
Haynes 25	0.12	1.5	0.5	20.0	10.0	Rem.	-	-	1.5	-	-	-	-	15.0	-	-	-

TABLE VII. MATERIALS PROPERTIES RECOMMENDED FOR USE IN DESIGN OF ROCKET P

MATERIAL			DENSITY	PROPERTY			
ALLOY	CONDITION	FORM	lb/cu.in.	SYMBOL	UNITS	-423F	-32
AISI Type 347 Stainless Steel	Annealed	Sheet	0.286	F_{tu}	ksi	210.0	187
				F_{ty}	ksi	45.0	40
				E_t	psi x 10^6	32.5	32
				α	in./in./°F x 10^{-6}	-	-
AM 350 Stainless Steel (b)	Cold Reduced and Tempered Cond CRT	Tubing	0.282	F_{tu}	ksi	-	280
				F_{ty}	ksi	-	250
				E	psi x 10^6	-	30
				α	in./in./°F x 10^{-6}	-	-
	Sub-zero Cool and Tempered Cond SCT	Tubing	0.282	F_{tu}	ksi	-	280
				F_{ty}	ksi	-	250
				E_t	psi x 10^6	-	30
				α	in./in./°F x 10^{-6}	-	-
AM 355 Stainless Steel	Sub-zero Cool and Tempered Cond SCT	Bar	0.282	F_{tu}	ksi	-	-
				F_{ty}	ksi	-	-
				E_t	psi x 10^6	-	-
				α	in./in./°F x 10^{-6}	-	-
	As Welded or As Brazed (b)	Bar	0.282	F_{tu}	ksi	210.0	310
				F_{ty}	ksi	110.0	81
				E_t	psi x 10^6	-	-
				α	in./in./°F x 10^{-6}	-	-
Rene' 41 Heat Resisting Alloy	Heat Treated ½ hr @ 1950F,WQ, 16hr @ 1400F,AC.	Sheet and Bar	0.298	F_{tu}	ksi	200.0	185
				F_{ty}	ksi	170.0	152
				E_t	psi x 10^6	32.6	32
				α	in./in./°F x 10^{-6}	-	-
	As Welded or As Brazed	Sheet	0.298	F_{tu}	ksi	177.0	165
				F_{ty}	ksi	126.0	115
				E_t	psi x 10^6	-	-
				α	in./in./°F x 10^{-6}	-	-
Hastelloy C Heat Resisting Alloy (c)	Annealed	Sheet	0.323	F_{tu}	ksi	-	-
				F_{ty}	ksi	-	-
				E_t	psi x 10^6	-	-
				α	in./in./°F x 10^{-6}	-	-
6061 Aluminum Alloy	Heat Treated to -T6	Sheet	0.098	F_{tu}	ksi	68.0	56
				F_{ty}	ksi	50.0	40
				E_t	psi x 10^6	-	11
				α	in./in./°F x 10^{-6}	-	10
	As Welded	Sheet	0.098	F_{tu}	ksi	50.0	31
				F_{ty}	ksi	29.0	19
				E_t	psi x 10^6	-	-
				α	in./in./°F x 10^{-6}	-	-

NOTES: (a) Explanation of Property Symbols: F_{tu} = Ultimate tensile strength, E_t = Modul
F_{ty} = Tensile yield strength (0.2% offset),
(b) As Welded or As Brazed properties for AM 355 stainless steel may also be used for
(c) Hastelloy C data from Reference (19), most other material property data from Refer

MMENDED FOR USE IN DESIGN OF ROCKET PROPULSION FLUID SYSTEM COMPONENTS.

PROPERTY		TEST TEMPERATURE											
SYMBOL	UNITS	-423F	-320F	-100F	ROOM	200F	400F	600F	800F	1000F	1200F	1500F	1800F
F_{tu}	ksi	210.0	187.0	118.0	75.0	66.0	58.0	55.0	54.0	48.0	41.0	-	-
F_{ty}	ksi	45.0	40.5	31.0	30.0	26.0	21.0	19.5	18.5	16.0	12.5	-	-
E_t	psi x 10^6	32.5	32.0	30.5	29.0	27.9	26.2	24.5	22.9	21.2	19.6	-	-
α	in./in./°F x 10^{-6}	-	-	-	8.9	9.3	9.4	9.6	9.9	10.2	10.6	-	-
F_{tu}	ksi	-	280.0	243.0	185.0	160.0	145.0	141.0	140.0	-	-	-	-
F_{ty}	ksi	-	250.0	215.0	147.0	132.0	123.0	119.0	105.0	-	-	-	-
E	psi x 10^6	-	30.5	29.6	28.7	28.1	27.0	25.9	24.5	22.8	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	-	-	-	-	-	-	-	-	-
F_{tu}	ksi	-	280.0	243.0	220.0	209.0	200.0	196.0	194.0	-	-	-	-
F_{ty}	ksi	-	250.0	215.0	192.0	171.0	158.0	149.0	142.0	-	-	-	-
E_t	psi x 10^6	-	30.5	29.6	28.7	28.1	27.0	25.9	24.5	22.8	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	6.1	6.3	6.6	6.8	7.1	7.2	-	-	-
F_{tu}	ksi	-	-	-	200.0	191.0	184.0	182.0	174.0	-	-	-	-
F_{ty}	ksi	-	-	-	165.0	150.0	135.0	130.0	119.0	-	-	-	-
E_t	psi x 10^6	-	-	-	28.7	28.0	27.0	25.9	24.5	22.8	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	6.2	6.4	6.6	6.8	7.1	7.2	-	-	-
F_{tu}	ksi	210.0	310.0	250.0	141.0	119.0	85.0	78.0	73.0	-	-	-	-
F_{ty}	ksi	110.0	81.0	63.0	54.0	50.0	46.0	44.0	38.0	-	-	-	-
E_t	psi x 10^6	-	-	-	-	-	-	-	-	-	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	-	-	-	-	-	-	-	-	-
F_{tu}	ksi	200.0	185.0	178.0	170.0	167.0	163.0	159.0	156.0	155.0	154.0	103.0	27.0
F_{ty}	ksi	170.0	152.0	138.0	130.0	126.0	124.0	122.0	121.0	120.0	119.0	90.0	23.0
E_t	psi x 10^6	32.6	32.3	31.6	31.0	30.5	29.7	28.7	27.5	26.0	23.9	19.7	14.3
α	in./in./°F x 10^{-6}	-	-	-	-	6.6	6.8	7.0	7.2	7.5	7.8	8.4	9.2
F_{tu}	ksi	177.0	165.0	143.0	130.0	125.0	117.0	114.0	111.0	110.0	105.0	94.0	-
F_{ty}	ksi	126.0	115.0	95.0	85.0	80.0	76.0	74.0	73.0	72.0	80.0	75.0	-
E_t	psi x 10^6	-	-	-	-	-	-	-	-	-	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	-	-	-	-	-	-	-	-	-
F_{tu}	ksi	-	-	-	121.0	115.0	110.0	105.0	101.0	99.3	97.2	69.0	31.7
F_{ty}	ksi	-	-	-	57.8	54.0	51.0	48.0	46.0	43.9	43.0	40.0	18.2
E_t	psi x 10^6	-	-	-	29.8	29.0	28.5	27.7	27.0	25.5	24.5	21.2	15.0
α	in./in./°F x 10^{-6}	-	-	-	6.0	6.3	6.7	7.0	7.3	7.5	7.7	8.0	8.5
F_{tu}	ksi	68.0	56.0	46.0	42.0	38.5	25.0	7.0	-	-	-	-	-
F_{ty}	ksi	50.0	40.5	36.5	35.0	32.0	21.0	3.5	-	-	-	-	-
E_t	psi x 10^6	-	11.5	10.3	9.9	9.7	8.9	6.9	-	-	-	-	-
α	in./in./°F x 10^{-6}	-	10.4	11.8	13.1	13.1	13.6	14.1	-	-	-	-	-
F_{tu}	ksi	50.0	31.0	29.0	27.0	25.0	-	-	-	-	-	-	-
F_{ty}	ksi	29.0	19.0	17.0	16.0	16.0	-	-	-	-	-	-	-
E_t	psi x 10^6	-	-	-	-	-	-	-	-	-	-	-	-
α	in./in./°F x 10^{-6}	-	-	-	-	-	-	-	-	-	-	-	-

mate tensile strength, E_t = Modulus of elasticity (tension),
ile yield strength (0.2% offset), = Coefficient of linear thermal expansion (from room temperature to temperature noted).
stainless steel may also be used for AM 350 stainless steel.
her material property data from References (18), (21) through (27), and (53).

The rocket propulsion fluid systems for which the factor of high temperature creep of materials is considered to present a problem are the pneumatic hot gas systems. The mechanical properties of alloys such as may be used for tubing and fittings for these systems are affected by the metallurgical changes which take place in these materials under the influence of elevated temperature and time. These changes are in many cases subject to definite physical laws. These laws generally follow a rate process equation, and from this basis several types of "parameters" have been developed which utilize the principle of some form of time-temperature relationship to enable long-time changes to be predicted from the results of relatively short-time tests. These parameters describe the rate effects, or changes in material properties, as a function of stress. One such widely used parameter is the Larson-Miller Parameter, which will be used for the presentation of creep-rupture properties of materials which may be used in the fabrication of pneumatic hot gas systems.

The Larson-Miller Parameter gives the following relationship for the effects of time and temperature on the creep-rupture properties of materials:

$$P = f(\sigma) = (T + 460)(\log t + C) \qquad [1]$$

where:

P = the Larson-Miller Parameter

σ = stress, psi

T = temperature, degrees Fahrenheit

t = rupture life, hours

C = a Constant

In the relationship shown by the above equation, a constant-stress plot of $\log t$ against the quantity $\frac{1}{(T+460)}$ should produce a series of straight line converging to a single point when $\frac{1}{(T+460)}$ is zero. At this point, $\log t$ is equal to C, and this value of C is theoretically the best Constant to use for the data involved. A value of 20 is frequently used for the Constant C in the Larson-Miller Parameter equation and has given satisfactory results, Reference (20). When enough experimental data are available, a derived value for the Constant C is used.

Creep-rupture properties for the candidate materials are given in Figure 1 in terms of the Larson-Miller Parameter in order to permit extrapolation of the data in terms of the effects of both temperature and time.

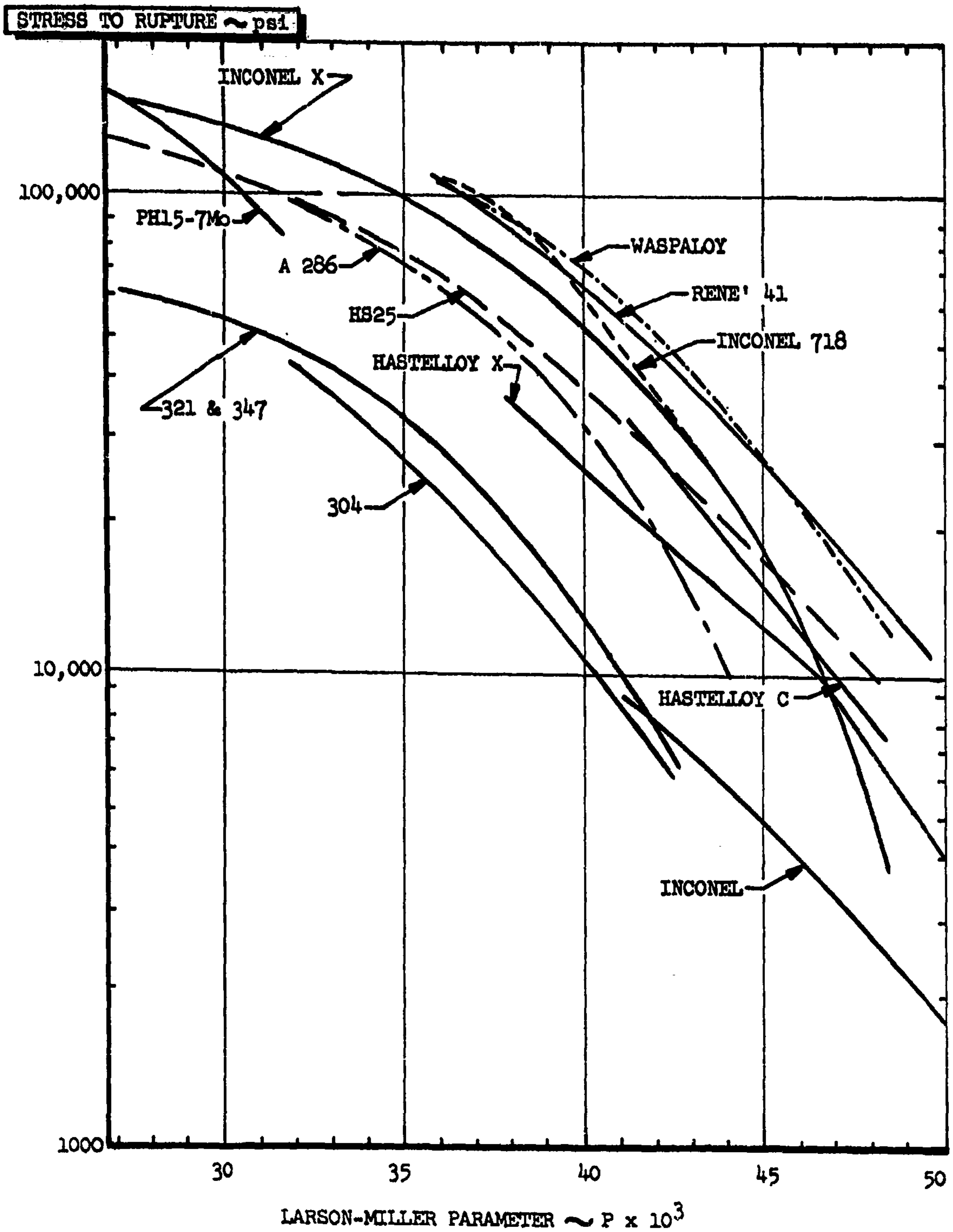


Figure 1. Creep-Rupture Properties of Selected Alloys.

Strength Properties of Brazing Alloys

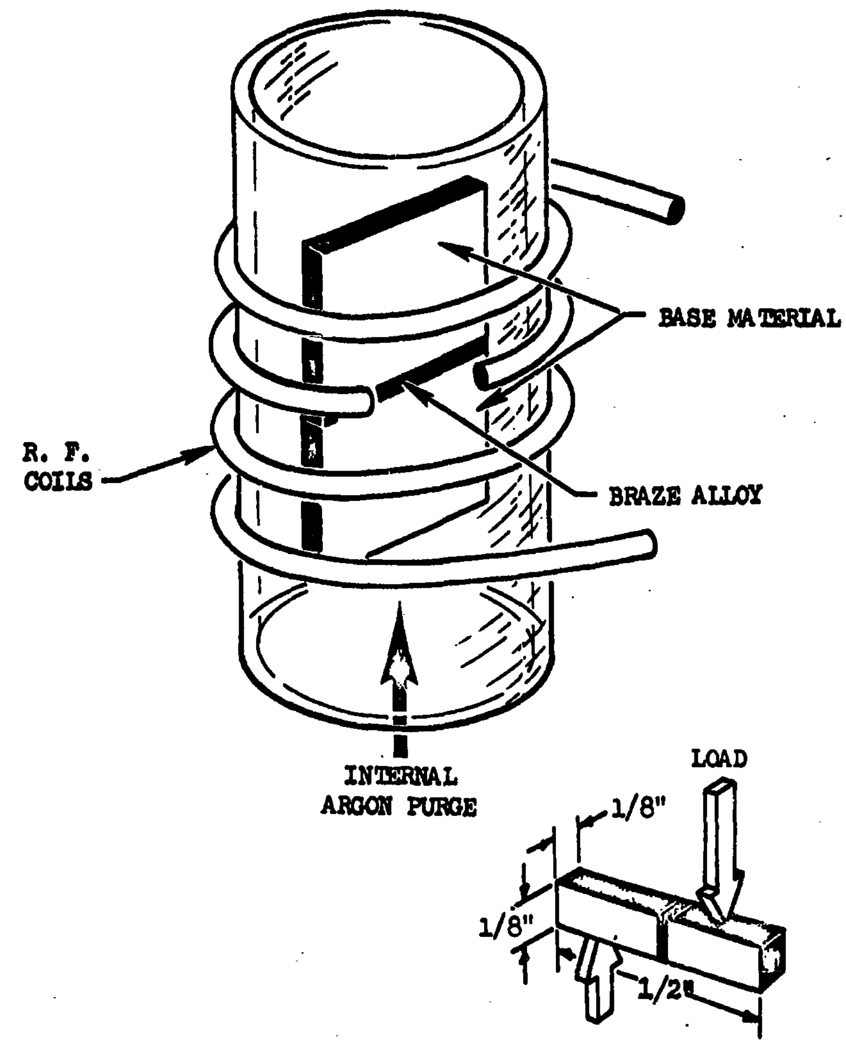
Candidate brazing alloys were selected for investigation under this program on the basis of brazing characteristics such as wettability and flow, on their compatibility with the alloys to be joined, their chemical compatibility with the system fluids, and their strength characteristics. The brazing characteristics and their compatibility with the alloys to be joined will be discussed later in this report in the section on BRAZING. Such data as were available from the literature survey on chemical compatibility have been discussed in the previous paragraphs. The strength properties of the candidate brazing alloys and the determination of shear strength values for use in the design of brazed tubing joints will be discussed in the following paragraphs.

The strength characteristics of the candidate brazing alloys were evaluated on the basis of their block shear strength. The block shear test method for evaluation of braze alloy strength has been established as a reliable, rapid and inexpensive method of joint strength evaluation for use at room temperature, sub-zero and elevated temperatures. A strength relationship has been found to exist between brazing alloys of similar base alloy compositions. Therefore, the block shear strength properties of the candidate brazing alloys can be determined on the basis of only a limited number of tests.

Specimen size is reasonably flexible, and a number of block shear test specimens can be cut from a single larger brazed joint section. Two sizes of test specimens were used for the block shear tests of this investigation. The room temperature test specimens were made by brazing together two pieces of the tubing system material, each 7/16 x 7/16 x 1/2 inch in size, butted together with the brazing alloy between them. The specimens for elevated temperature testing were made by brazing together two pieces of tubing system material, each 1/8 x 7/16 x 1/4 inch in size. The joint was brazed by induction heating in an argon atmosphere as shown in Figure 2, after which the brazed joint section was cut into block shear test specimens of the sizes shown in Figure 3.

A complete screening program to determine the characteristics of a variety of braze alloy compositions has been conducted by the NAA/LAD Metallic Materials Laboratory during the past few years as part of the development of the X-15 and XB-70 air vehicles. The evaluation has included block shear tests at temperatures from ambient to 1000 F. The silver-base braze alloys and several of the gold-base braze alloys being considered for use under this program were investigated at that time. The results of previous tests on alloys of interest to this rocket fitting development program (References (28) to (46), have been correlated, and the results are presented in Figures 3 and 4, along with the test values which were determined under this current USAF program.

Block shear strength tests were performed at temperatures from -320 F to 1500 F. Rene' 41 alloy specimens with Palladium-Nickel braze alloy joints were evaluated over the entire temperature range. The results of these tests are presented in Figures 3 and 4, and in Table VIII. This braze



NOTE: A 30 SECOND BRAZE
CYCLE WAS USED.

TYPICAL TEST SPECIMEN

Figure 2. Induction Brazing Setup for Block Shear Specimen Fabrication.

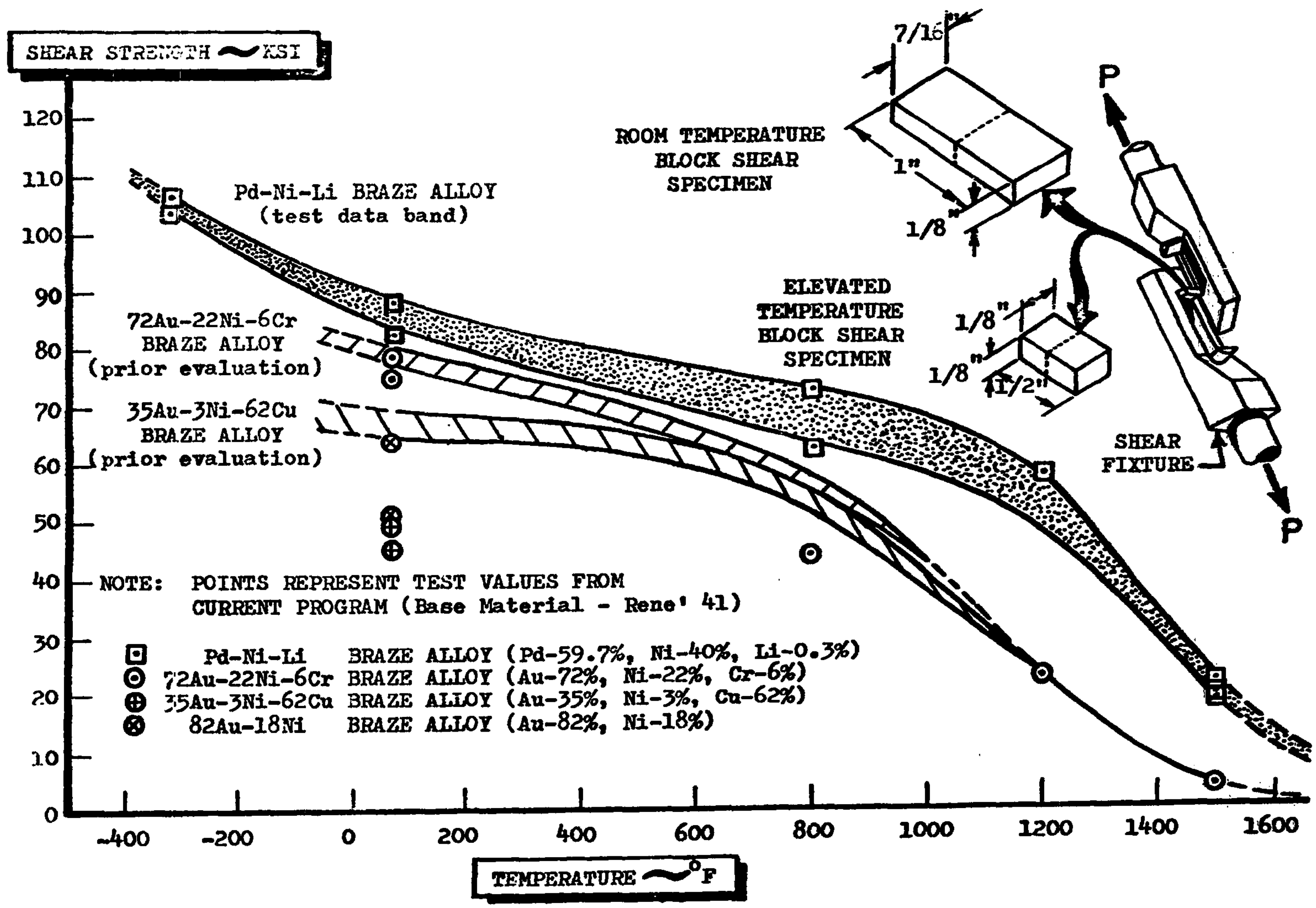


Figure 3. Block Shear Strength Vs. Temperature for Palladium-Nickel-Lithium and Gold-Nickel Base Braze Alloys. Correlation of Data from NAA Tests.

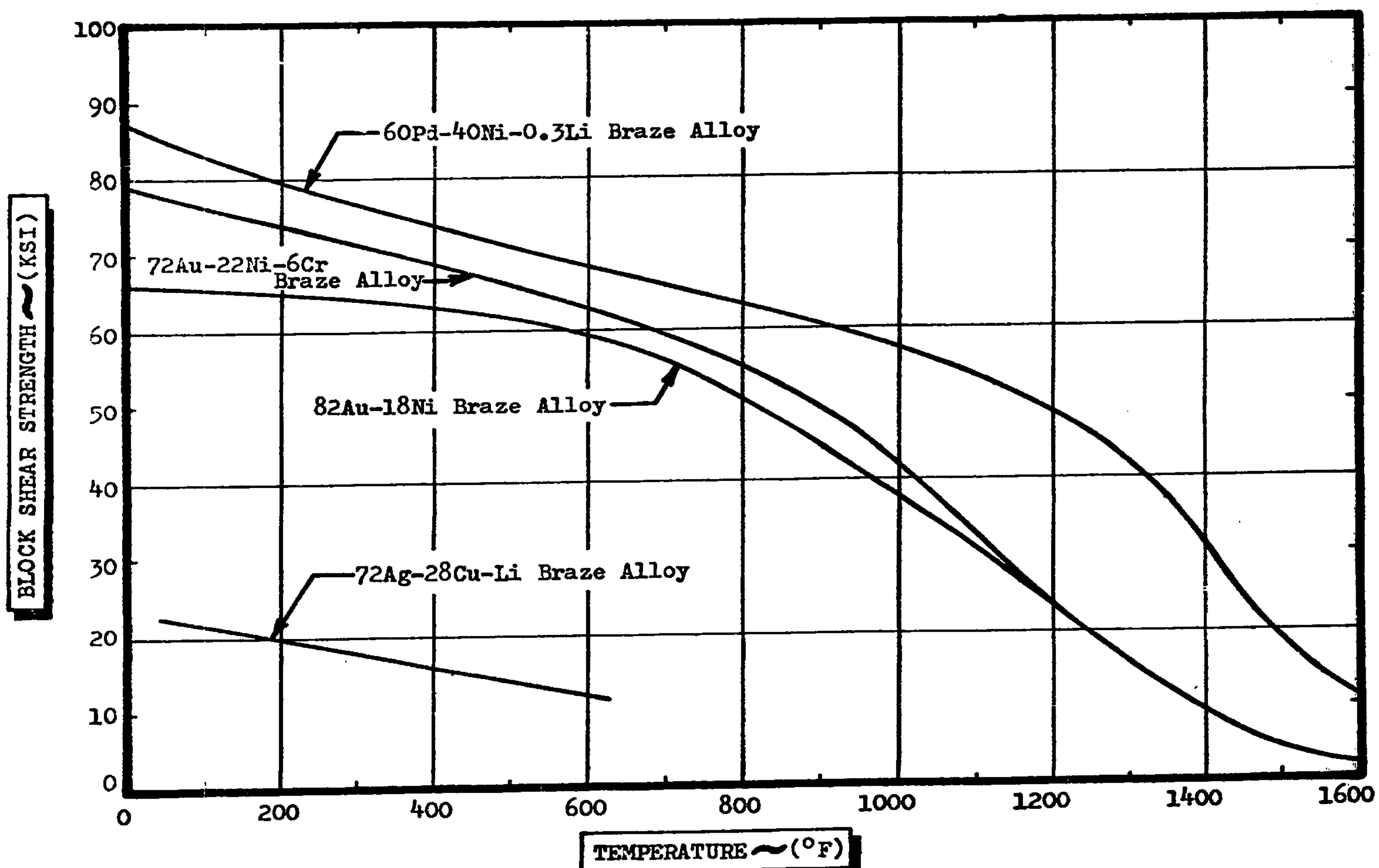


Figure 4. Block Shear Strength Vs. Temperature Properties of Braze Alloys for Use in Design of Tube Joints for Rocket Propulsion Fluid Systems.

TABLE VIII. BLOCK SHEAR STRENGTH EVALUATION OF 60Pd-40Ni-0.3Li BRAZE ALLOY

SPECIMEN NUMBER	JOINT AREA (sq. in.)	TEST TEMPERATURE	ULTIMATE SHEAR LOAD (lb)	ULTIMATE SHEAR STRENGTH (psi)	AVERAGE SHEAR STRENGTH (psi)
21	.0143	-320 F	1495	104,545	105,500
22A	.0121		1290	106,611	
2	.0495	Room	4100	82,828	85,700
3	.0454		4025	88,656	
15	.0198	800 F	1390	72,202	67,500
15A	.0220		1385	62,954	
1A	.0208	1200 F	1195	57,451	57,450
13A	.0191	1500 F	360	18,324	19,900
13B	.0173		375	21,675	
14A	.0191		362	18,905	

Note: Base Material was Rene' 41 Alloy.
All sheared braze surfaces appeared void free.

alloy exhibited the highest block shear strength properties of the brazing alloys being considered for use in this program.

The gold-base brazing alloys were also evaluated with Rene' 41 alloy block shear specimens. The gold-nickel-chromium alloy, 72Au-22Ni-6Cr, was tested at temperatures from ambient to 1500 F. Two other gold-base brazing alloys, the gold-copper-nickel alloy, 35Au-3Ni-62Cu, and the gold-nickel eutectic alloy, 82Au-18Ni, were tested only at ambient temperature during the present investigation. The 82Au-18Ni alloy had been tested at elevated temperatures during the earlier NAA brazing alloy screening programs, References (46) to (48). The results from all the block shear tests of the gold-base brazing alloys are shown in Figures 3 and 4. The data from the tests conducted on the gold-base brazing alloys during Phase I of the present program are shown in Table IX.

Block shear strength tests were not conducted for the Ni-Cr-B braze alloys because the poor performance of these alloys in the preliminary wetting and flow tests (to be discussed under BRAZING) eliminated them from further consideration for brazing Rene' 41 tubing. The Au-Ni-Cr and Au-Ni alloys and the 60Pd-40Ni-0.3Li alloy were selected for further evaluation for brazing Rene' 41 tube joints.

The block shear strength of Type 347 stainless steel joints brazed with the 72Ag-28Cu+Li alloy, and also of AM 350 stainless steel joints brazed with 72Ag-28Cu+Li alloy, were not determined under this program. Such joints had been fully tested by NAA under previous screening programs, References (33), (34), and (49) to (51). Therefore, the block shear strength values for such joints shown in Figure 4 are taken from the material property values used for NAA for design purposes, Reference (18).

2.3 AVAILABILITY AND WORKABILITY OF TUBE AND FITTING MATERIALS

The factor of availability of a material in the form of tubing and the workability of the material are to a large extent interdependent. Easily worked materials can be formed into all sizes of tubing; but only limited tubing sizes and wall thicknesses can be made from material that is difficult to work.

Tubular shapes are produced by two main processes. Seamless tubing is made by drawing pierced billets or tubular extrusions over mandrels. Welded tubing is produced by forming suitably sized strips into a tubular shape and then welded the edges together. This tubing can be used in the as-welded condition, or it can be redrawn after welding to produce a uniformly sized product with the weld area reworked and smoothed. Tubing which has been welded and cold redrawn, known as "welded and drawn" tubing, is generally considered to be equivalent to seamless tubing.

A great many alloys can be produced in seamless tubular shapes on an experimental basis. Commercially available candidate alloys which can be procured in the form of seamless tubing include the type 300 series austenitic stainless steels, many of the Hastelloy type alloys, Inconel and Inconel X, aluminum and most of the aluminum alloys, and tantalum. Welded

TABLE IX. BLOCK SHEAR STRENGTH EVALUATION OF GOLD-BASE BRAZE ALLOYS

SPECIMEN NUMBER	JOINT AREA (sq. in.)	TEST TEMPERATURE	ULTIMATE SHEAR LOAD (lb)	ULTIMATE SHEAR STRENGTH (psi)	VOIDS IN SHEARED BRAZE SURFACE (percent)	CORRECTED BRAZE ALLOY SHEAR STRENGTH (a) (psi)	AVERAGE CORRECTED SHEAR STRENGTH (psi)
			72Au-22Ni-6Cr ALLOY				
7	.0488	Room	3480	71,311	5	74,876	76,700
8	.0521		3410	65,451	20	78,541	
16A	.0154	800 F	676	43,895	0	43,895	43,895
16	.0153	1200 F	330	21,700	5	22,800	22,800
9	.0193	1500 F	59	3,056	20	3,820	3,820
			35Au-3Ni-62Cu ALLOY				
4	.0464	Room	2285	49,245	0	49,245	47,200
5	.0424		1825	43,042	5	45,194	
			82Au-18Ni ALLOY				
11	,0449	Room	2100	46,770	10	51,447	57,700
12	.0504		3070	60,912	5	63,957	

Note: (a) Ultimate Shear Strength values corrected for void braze areas.
Base Material was Rene' 41 Alloy.

and drawn tubing can be produced in a wider variety of alloys, including AM 350 stainless steel and Rene' 41 alloy.

The delivery time of tubing made from many of the special alloys, such as Rene' 41, depends of course on the dimensional size and on the amount ordered. Medium quantity lots can, in general, be supplied more economically and more quickly than very small or or very large orders. Non-standard sizes are very difficult to obtain, and the manufacture of special dies would be warranted only for very large quantity orders. The small quantities usually required for experimental purposes frequently can be obtained only by accepting overruns or extras left over from prior production lots. However, in the case of some materials, such as the type 300 stainless steels, just about any size and wall thickness is available from warehouse stock.

2.4 MACHINABILITY OF FITTING MATERIALS

The fittings which are used to make the connections between the system tubing are in the form of short sleeves. The sleeves for the welded joints are usually made by expanding short lengths of tubing an appropriate amount. The sleeves for the brazed joints must be machined to obtain the required dimensions and precision tolerances required for the bore and the brazing alloy grooves. The brazing sleeves are usually machined from tube or solid bar.

Machinability is generally a function of strength and the strain hardenability of a material. Some measure of the machinability of a material can be obtained from an overall machinability rating. This rating is derived experimentally by the force and power required to remove a given amount of material in a given time by various machining processes. The ratings are compared to a value of 100 for a free-machining steel. The following machinability ratings for some candidate alloys are based on data from the technical literature and also from tests conducted in the experimental machine shops at North American Aviation, Inc.

Candidate Material	Relative Machinability Rating
Type 316 stainless steel	50
Type 321 stainless steel	50
Type 347 stainless steel	50
Inconel	40
Inconel X	20
Waspaloy	20
Rene' 41	15
Titanium & Titanium Alloys	30 - 60
Aluminum & Aluminum Alloys	100 - 200

2.5 CONCLUSIONS ON MATERIALS SELECTION

Of all the candidate materials for rocket propulsion fluid system tubing and fittings, titanium alloys have the best strength/weight ratio.

However, titanium and its alloys have a very low chemical compatibility with many rocket propulsion system fluids and due to the many fabrication problems their use is not recommended.

The type 300 series austenitic stainless steels in the annealed condition have generally good chemical compatibility with the rocket propulsion system fluids. These alloys have a low yield strength/density ratio; but, they have sufficient strength to be usable for rocket propulsion fluid system lines at room and moderately elevated temperatures, and they have quite good strength and excellent toughness at the low cryogenic temperatures. The two alloys of this series which can be used in the "as-welded" or "as brazed" condition, types 321 and 347 stainless steels, are readily available in the sizes generally required for use in rocket propulsion fluid systems. The information presented in Table III, page 7 , shows that these two alloys, of all the type 300 series stainless steels, have the best chemical compatibility with all of the rocket propulsion system fluids. On the basis of the available information, the type 347 stainless steel is considered to be the most suitable for all the fluids except fluorine, and is recommended for service from cryogenic temperatures up to temperatures in the range from 200 F to 600 F.

The aluminum alloys because of their low weight are definitely useful for low and moderately elevated temperature and low pressure applications wherever they are chemically compatible with the system fluids. Difficulties which were encountered in joining them by the welding and brazing techniques of this program led, at first, to the virtual elimination of the aluminum alloys as candidate materials. However, a successful procedure for semi-automatic TIG welding of "in-place" joints in aluminum tubing was developed later in the program. Therefore, certain of the aluminum alloys, such as 6061, can be recommended for rocket propulsion fluid system usage.

Potential candidate materials for high temperature service were tantalum and a group of heat-resisting superalloys consisting of Rene' 41, the Hastelloys , Waspaloy, and Inconel 718. Rene' 41 was selected as the recommended material from the latter group for several reasons. It had a greater potential chemical compatibility with the rocket system fluids than did the other materials in the group, notably the Hastelloys. Rene' 41 was also more readily available in the form of tubing than were some of the other materials at that time period. Finally, Rene' 41 in the "as welded" and "as brazed" conditions has satisfactory strength for use in this program, and responds rapidly to aging at elevated temperatures, thus recovering much of the strength lost in joining, References (24), (25) and (52). Inconel 718 was found to have extremely low strength in the annealed and the "as-welded" conditions. Inconel 718 is reported to be very sluggish in its aging response, and thus would take a long time to recover the strength lost during the joining process, Reference (53). Tantalum would be a very suitable material from the point of view of chemical compatibility, but its cost is so high as to preclude widespread use except in cases where no other material would be suitable.

One other material had been selected for testing under this program along with the Type 347 stainless steel and the superalloy Rene' 41. This was the precipitation hardening stainless steel AM 350. AM 350 had been

selected because of its generally good chemical compatibility and its excellent strength-to-weight ratio. This material was, therefore, recommended for inclusion in this program. The fittings, or sleeves, for the welded joints in AM 350 tubing systems are made by expanding short lengths of the tubing to be joined. The brazing fittings are machined from AM 355 stainless steel bar stock.

It is believed that the materials selected for development and testing as fittings under this program, while not in common usage for rocket propulsion fluid systems at the present time, all show promise for such application in the near future. Results obtained with these materials should be capable of being extrapolated to other service conditions to a useful extent.

3. STRUCTURAL ANALYSIS

3.0 GENERAL REQUIREMENTS

The components of rocket fluid systems for which a stress analysis is to be conducted under this program are the tubing lines and the fittings, or joining sleeves. Joining techniques to be considered are the brazing and the welding processes. The environment to be dealt with consists of high internal pressures, and also intensive heating and cooling which causes a sharp thermal gradient across the tube or fitting wall.

For engineering purposes the analysis is made in accordance with the following considerations:

(1) The tubes are treated as thick shells subject to both high radial temperature variation and internal pressure.

(2) The loads are rotationally symmetrical about the axis of rotation.

(3) The principle of superposition operates within the elastic range; that is, the elastic and thermal stresses can be combined algebraically.

3.1 TUBING ANALYSIS

The following equation governing the distribution of stresses in a tube are used for tubing stress analyses. The derivation of these equations are shown in Reference (54).

The maximum circumferential, or hoop, stress is:

$$(\sigma_\theta)_{max} = \frac{b^2 + a^2}{b^2 - a^2} p_i \qquad [1]$$

where:

a = inside diameter of tubing

b = outside diameter of tubing

p_i = internal (system) pressure

Thermal stresses are produced in the tubing by the temperature difference between the inner and outer surfaces of the tubing wall. These thermal stresses can be calculated by the following equation:

$$\sigma_t = \pm \frac{\alpha E (T_i - T_o)}{2(1-\mu)} \qquad [2]$$

where: α = linear coefficient of thermal expansion of tubing material

T_i = temperature on inner surface of tube wall

T_o = temperature on outer surface of tube wall

μ = Poisson's ratio of tubing material

The upper sign of the $\pm$ sign in Equation [2] applies to the thermal stress at the outer surface of the tube wall, and the lower sign to the thermal stress at the inner surface. When the temperature of the tube wall inner surface is less than that of the tube wall outer surface ($T_i < T_o$), the outer surface thermal induced stress is compressive and the inner surface thermal stress is tensile, References (54) and (55).

The principle of superposition can be used to combine the thermal induced stresses on the tubing wall with the stresses produced by the internal pressure in the tube in order to determine the critical stress in the tubing and its location. In the case noted above, where the tube wall outer surface is hotter than the inner surface, the critical combined stress is a tension stress on the inner surface. Where the thermal gradient is large, the critical combined stress can reach the yield strength of the material as a limiting value. The redistribution of local stresses should be considered, especially during equilibrium heating conditions, References (56) and (57).

If the wall thickness of the tubing is defined by $b/a \lesssim 1.5$, and the maximum circumferential stress, (σ_θ) max, is defined as the material yield strength, F_{ty}, for the proof loading condition or the tensile ultimate strength, F_{tu}, for the burst condition; by Reference (58), Equation [1] can be used to calculate the tube wall thickness required for a given internal pressure and temperature environmental condition. The following equation, which is derived from Equation [1], can be used to calculate the wall thickness:

$$t_t = \left(\frac{D}{2}\right)\left(1 - \sqrt{\frac{F_t - P_i}{F_t + P_i}}\right) \qquad [3]$$

where: $t_t = b - a$

D_t = nominal tube diameter

F_t = material yield (proof) or ultimate (burst) strength

The material strengths, F_{tu} and F_{ty} , are temperature dependent. Therefore, the material strength values for the maximum service temperature, as shown in Table VII, should be used in the calculation of the tubing wall thickness. The use of the short-time high temperature strength values is satisfactory for rocket systems where the time at temperature and under load is relatively short. For systems where the tubing may be under load at high temperatures for more than one or two hours total time, the creep strength values shown in Figure 1 should be used.

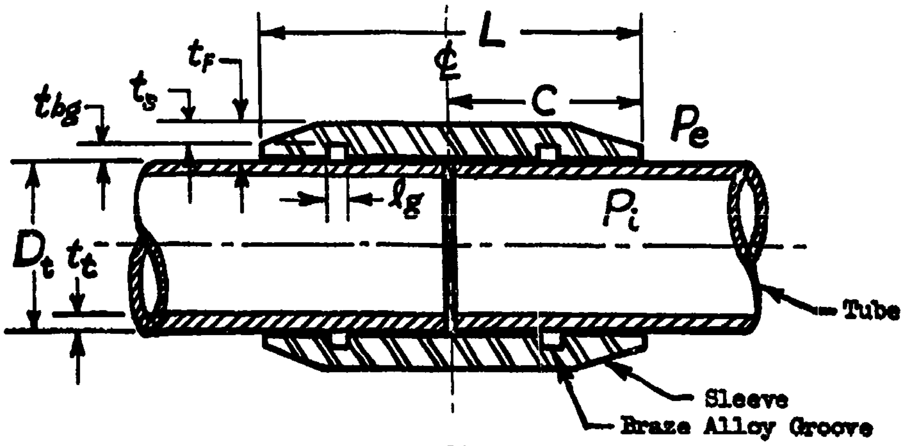
The theoretical value for tube wall thickness calculated by use of Equation [3] should be increased by ten percent to compensate for the effects of minor material imperfections and other factors which might reduce the tubing strength or adversely affect the service life. Finally, the actual wall thickness specified should be a standard size for the particular tubing material. If the calculated size is between two standard sizes, the heavier, or thicker, size should be specified.

3.2 FITTING (SLEEVE) ANALYSIS

Wall Thickness

The wall thickness specified for the fittings, or sleeves, for the welded tube connections is normally the same as the wall thickness of the tubes being joined. In most cases, the weld joint sleeve fitting will be made by expanding the diameter of a short length of the same tubing just enough so that it can be slipped over the tubing. The procedures and tolerances for this will be further discussed in the section on the weld joining process.

The wall thickness of the braze joint fittings, or sleeves, must be greater than that of the weld fittings in order to provide for the internal circumferential grooves required to hold the brazing alloy. In order to provide for the stress concentration due to the brazing alloy grooves and for other imperfections, the material strength allowable used as F_t in Equation [3] should be 2/3 of the values given in Table VII.



Fitting Sleeve Length

The length of the weld fitting sleeve is not too critical, and a sleeve is not required for some weld joint designs. When it is used, however, the sleeve should be sufficiently long that it can give support to the heat affected zone of the joint. This is the length of the tube adjacent to the weld bead which has been softened by the welding heat.

The length of the braze fitting sleeve is critical to the strength of the brazed joint. The primary concern is that the fitting sleeve withstand the load applied along the axis of the tube. This load, which tends to pull the tube ends out of the fitting sleeve, is the total of the stress produced by the internal pressure in the tube, the stresses due to temperature effects on different sections of the tubing system, and the stresses caused by mechanical effects due to warping of the structure which supports the tubing system. This total axial load along the tubing axis cannot exceed the tensile strength of the tubing material or the tubing itself would fail before the joint. The tensile strength of the tubing is given by:

$$\sigma_{axial} = F_t \pi D_t t_t \qquad [4]$$

The axial strength of the brazed joint is given by:

$$\sigma_{axial} = F_s \pi D_t (C - N\ell_g) \qquad [5]$$

where:

F_t = tensile ultimate or tensile yield strength of tube material ("as-welded" or "as-brazed" condition)

F_s = shear strength of brazing alloy

D_t = nominal outside diameter of tubing

C = half length of braze fitting sleeve

ℓ_g = width of braze alloy reservoir groove in sleeve

N = number of braze alloy grooves in length C

Since the braze joint need equal only the strength of the tubing, Equations [4] and [5] may be combined to give the half length of the braze fitting sleeve as:

$$C = \frac{F_t t_t}{F_s} + N\ell_g \qquad [6]$$

and the total length of the braze fitting sleeve is:

$$L = 2C = \frac{2F_t t_t}{F_s} + 2N\ell_g \qquad [7]$$

To this length must be added the total length of the locating lands if the braze fitting sleeve is designed with a controlled capillary. In order to distribute the shear stress more evenly along the length of the brazed joint,

the ends of the braze fitting sleeve should be tapered in thickness as shown in the sketch on page 99. See Reference (59).

The braze joint fitting sleeves used in this program were designed for internal preplacement of the brazing alloy. Such preplacement permits the joint to be easily assembled in any position without danger of loss of the braze alloy ring or movement of the ring away from the joint capillary.

The 1/8 inch diameter tube joints were brazed with a simple through-bore fitting sleeve, with the braze alloy ring butted between the ends of the tubes to be brazed. The fitting sleeves for all of the tubing joints 0.250 inch in diameter and larger were designed with an internal braze alloy retention groove. Because of difficulties which would be encountered in machining the sleeves and in assembly of the joint, it is recommended that 0.250 inch diameter tube fitting sleeve be the smallest size using internal braze alloy retention grooves. The location of this groove with respect to the length of the joint capillary has been determined in previous investigations conducted by the Contractor during the development of the hydraulic fluid tubing systems for the X-15 and XB-70 aircraft, References (60) to (64). The braze alloy retention groove should always be located slightly closer to the interior end of the joint capillary than to the outer end. This provides a longer distance for the braze alloy to flow to reach the edge of the fitting sleeve than to the sleeve center, thereby permitting assurance of full braze alloy flow to be determined by a visual inspection of the joint.

The diameter of the braze alloy retention groove and the length of the groove must be selected so that the notch effect of the groove is minimized to avoid fracture of the fitting sleeve under load. The dimensions of the groove must also be chosen to provide for the containment of sufficient braze alloy to assure complete filling of the joint capillary under any brazing condition. A braze alloy groove volume of approximately three to seven times the maximum joint capillary volume is recommended. The dimensions of the fitting sleeves for the brazed joint Qualification Test specimens are given in Table XIV, page 99.

The use of locating lands at the center and ends of the fitting sleeve serves to align the tube ends and provides a positive capillary dimension in the assembled joint. The locating lands should have sufficient area to withstand the socket loads applied by misalignment of the installed tubing to be joined. When a sleeve is designed with locating lands, the overall length of the sleeve will be the length of the braze capillary calculated according to the procedure given on the preceding page plus the total length of the locating lands.

3.3 DETERMINATION OF TUBING SIZES

Based on the foregoing stress analysis procedures, data were prepared in the form of curves showing the relationship between tubing diameters and wall thicknesses for various system pressures and temperatures. The data are presented for 6061 aluminum alloy, AISI Type 347 and AM 350

stainless steels, and Rene' 41 nickel-base alloy tubing. These data are shown on Figures 5 through 9.

The individual tubing sizes which were to be used in the Phase II Qualification Test Program were selected to represent both the minimum and maximum tube sizes normally used in each particular fluid system. The three inch diameter size for the AISI Type 347 stainless steel tubing was the largest size propellant system tubing for which testing was contractually required, even though fitting connection designs were to be prepared later for larger tubing sizes, as determined to be feasible, up to a maximum of 16 inches diameter.

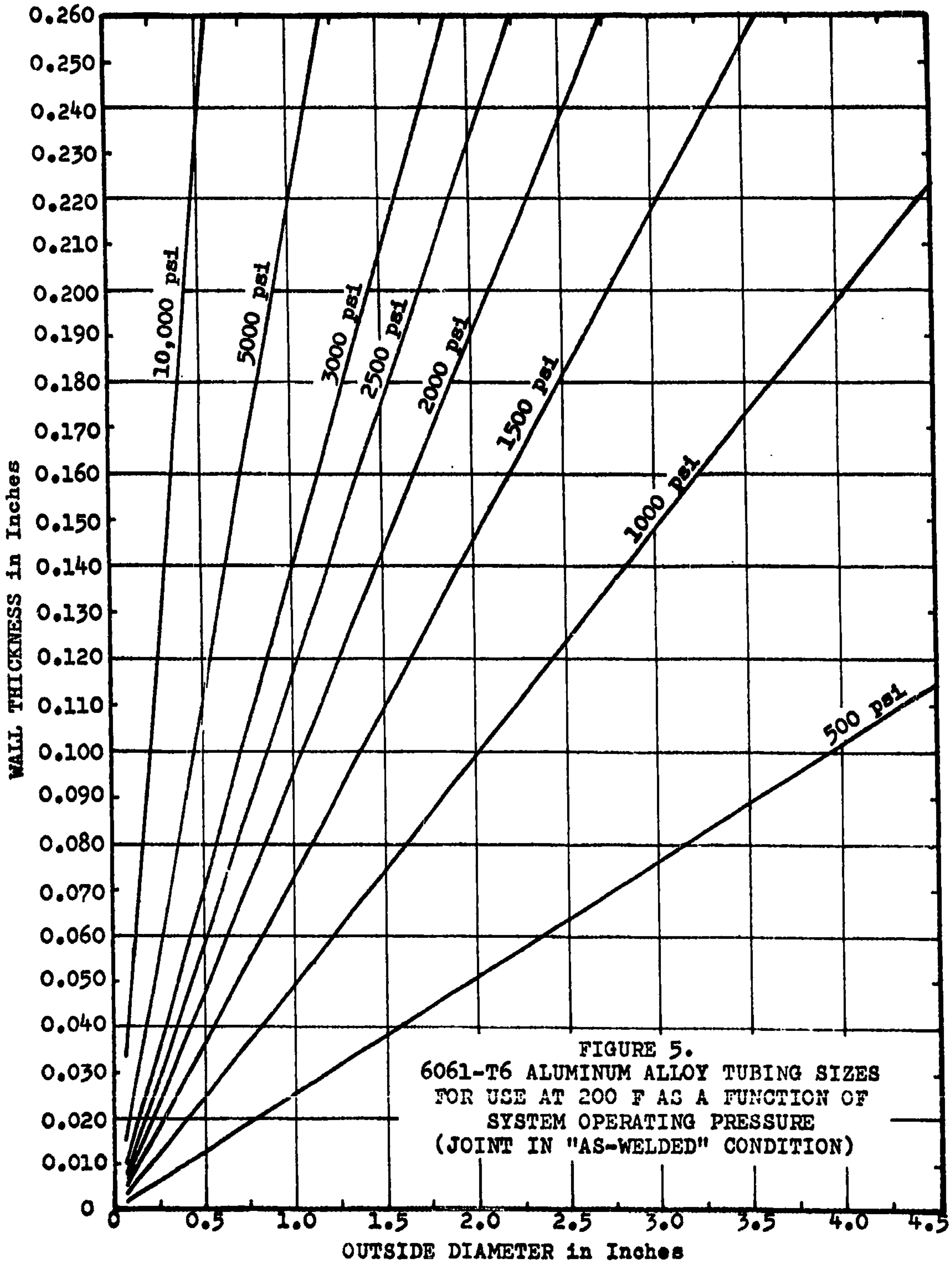


FIGURE 5.
6061-T6 ALUMINUM ALLOY TUBING SIZES FOR USE AT 200 F AS A FUNCTION OF SYSTEM OPERATING PRESSURE (JOINT IN "AS-WELDED" CONDITION)

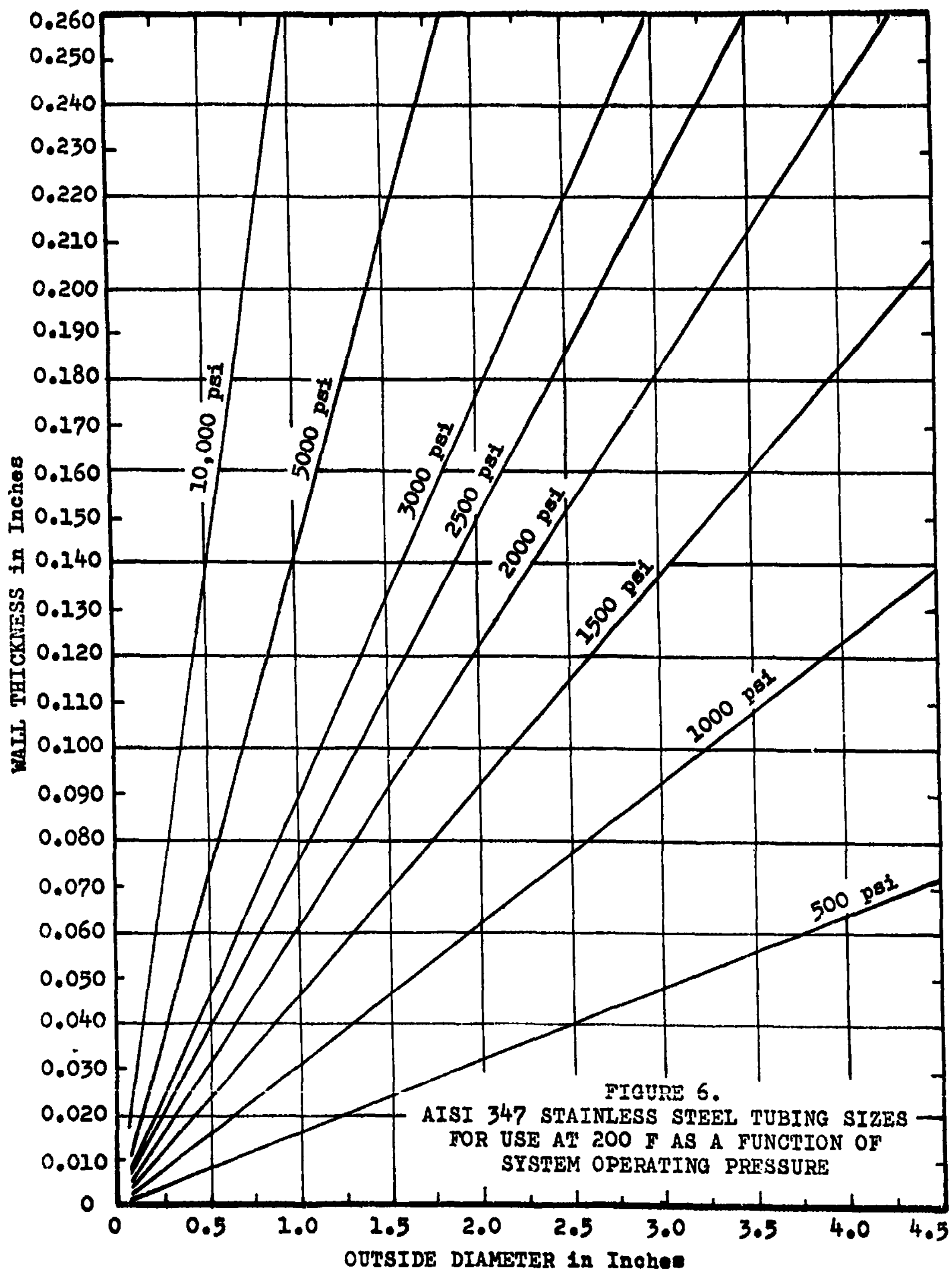


FIGURE 6.
AISI 347 STAINLESS STEEL TUBING SIZES FOR USE AT 200 F AS A FUNCTION OF SYSTEM OPERATING PRESSURE

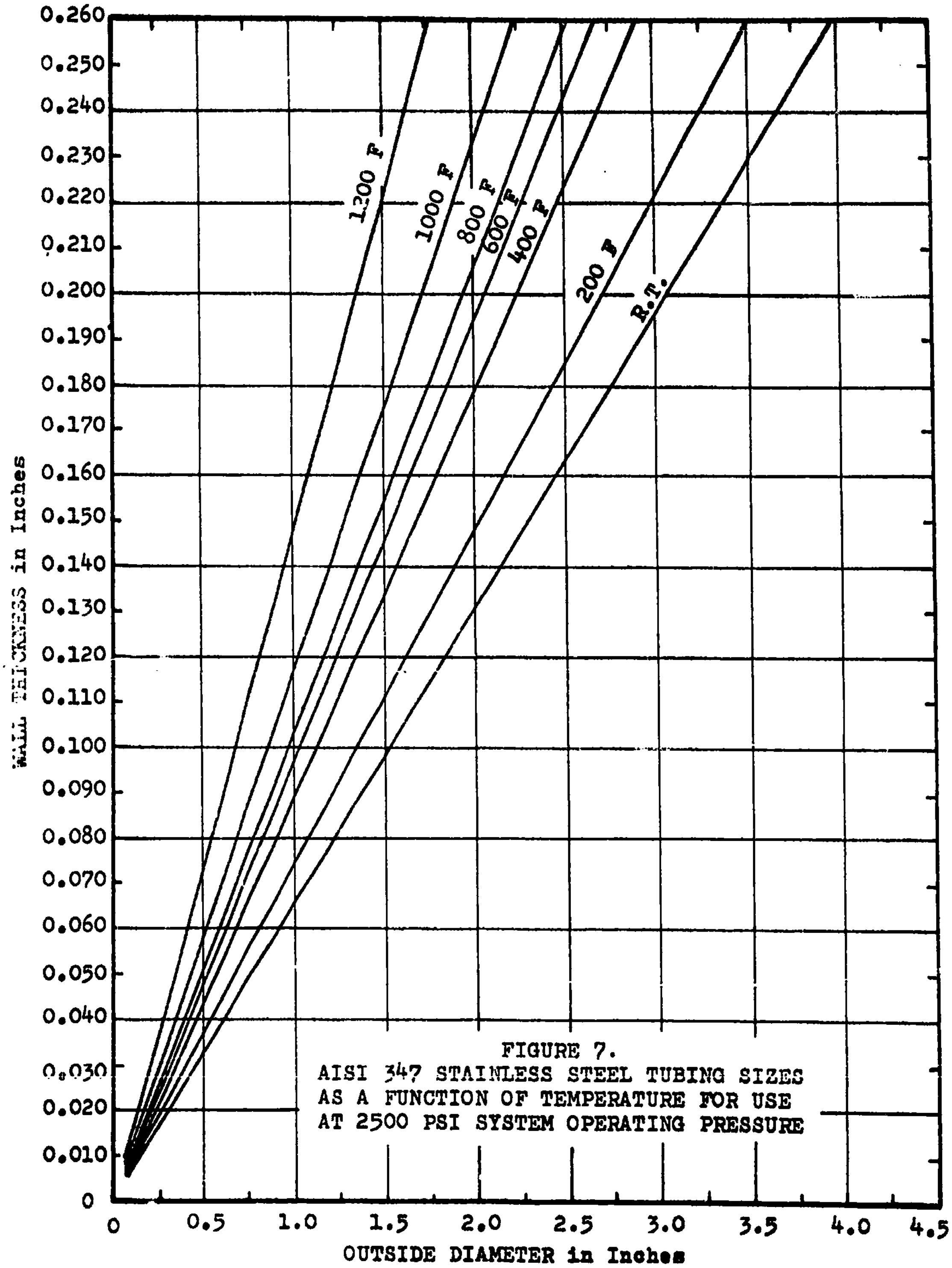


FIGURE 7.
AISI 347 STAINLESS STEEL TUBING SIZES AS A FUNCTION OF TEMPERATURE FOR USE AT 2500 PSI SYSTEM OPERATING PRESSURE

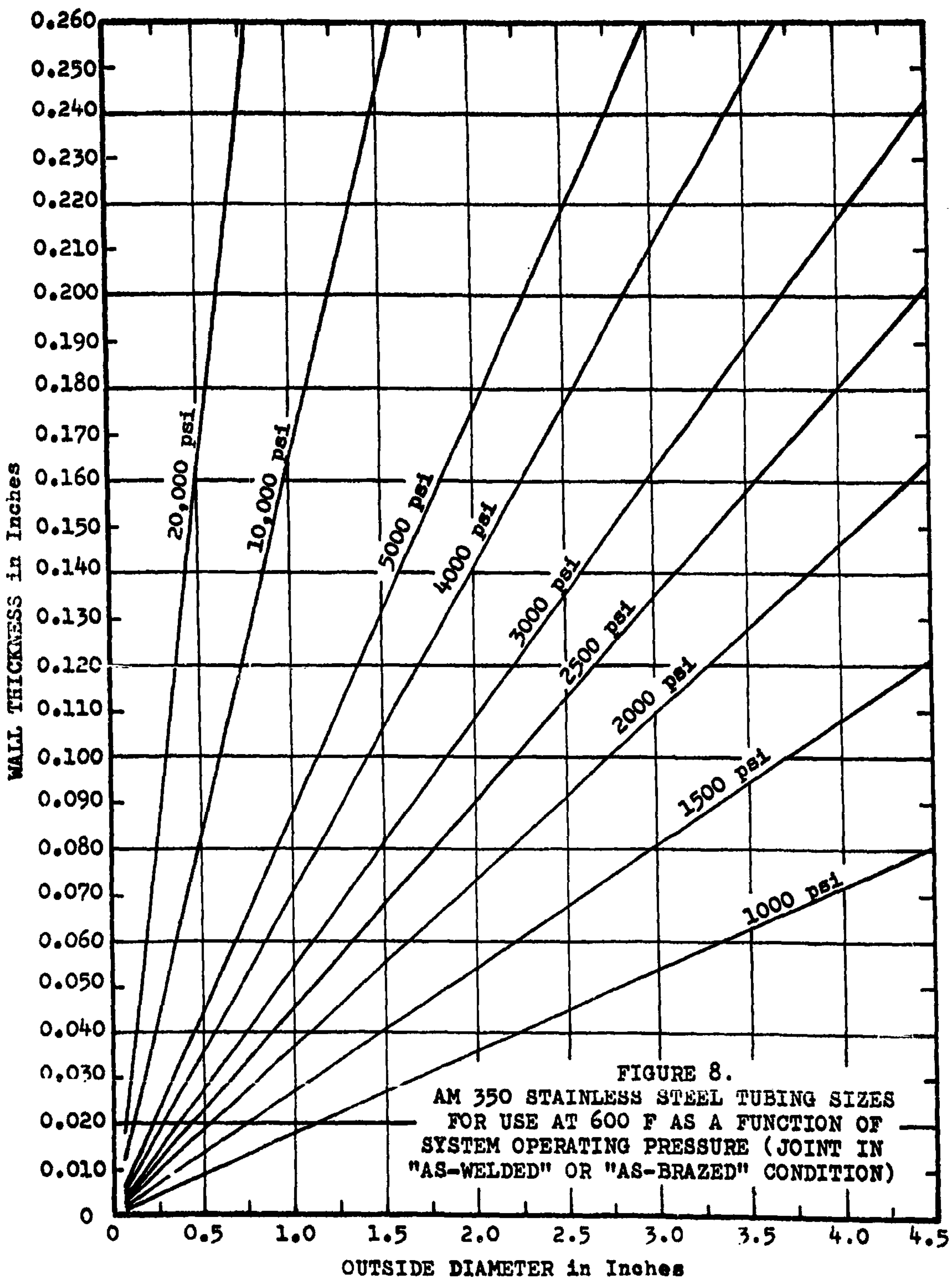


FIGURE 8.
AM 350 STAINLESS STEEL TUBING SIZES FOR USE AT 600 F AS A FUNCTION OF SYSTEM OPERATING PRESSURE (JOINT IN "AS-WELDED" OR "AS-BRAZED" CONDITION)

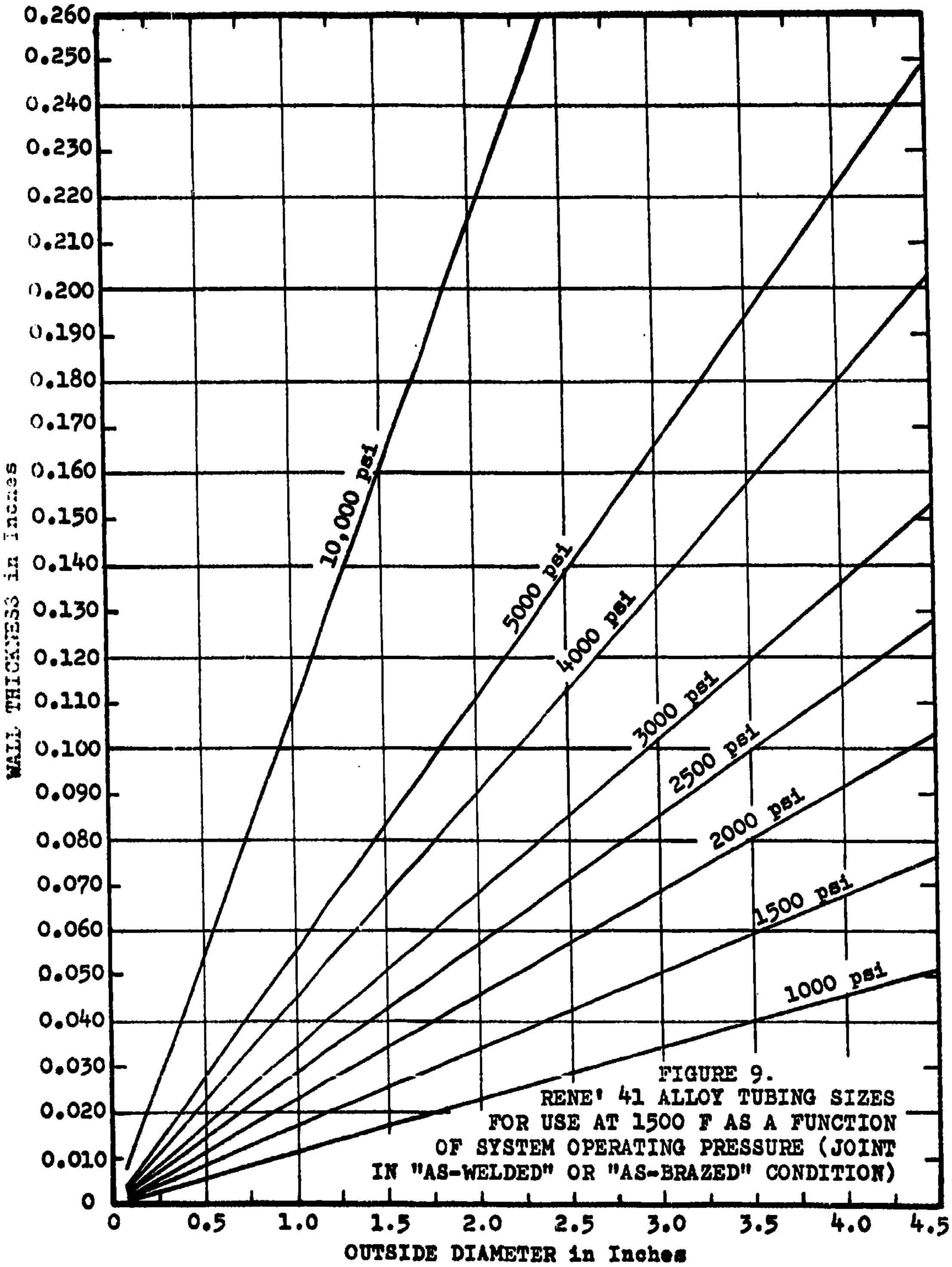


FIGURE 9.
RENE' 41 ALLOY TUBING SIZES
FOR USE AT 1500 F AS A FUNCTION
OF SYSTEM OPERATING PRESSURE (JOINT
IN "AS-WELDED" OR "AS-BRAZED" CONDITION)

4. TUBE WELDING

4.0 GENERAL

Fusion welding is a preferred method of joining tubing for rocket fluid systems because of its inherent advantages over many other methods of assembly. Welded connections require minimum weight addition at the joint, they have good strength at elevated temperatures, good fatigue properties because of the minimal change in section at the joint, and they require small accessibility space for the joining tooling. A very favorable asset of the welded joint is that usually only one material is involved; therefore, the problems of corrosion and interactions between dissimilar materials are minimized. This is an extremely important consideration in the development of joint systems for compatibility with rocket propulsion fluids having high degrees of chemical activity.

Special semi-automatic welding equipment and procedures have been developed for "in place" joining of rocket propulsion fluid system tubing. These techniques can be used for bench work in the shop and for final assembly or repair of the tubing lines in the vehicle itself.

New welding equipment has been designed and built, and other existing equipment has been modified, in order to meet the particular requirements of this program. The effort also included the establishment of welding procedures and parameters. The application of these tools to the joining of the selected tubing materials was accomplished and the required weld-joint specimens for the Qualification Test Programs were fabricated and tested.

4.1 WELDING TOOLS

Phase I Tooling

Two tube welding units were used in the Phase I part of this program. One unit was an existing tool which had been built by NAA/LAD during the initial "in house" work on development of "in place" tube welding, Reference (65). This tool was suitable for joining small diameter tubing up to a maximum diameter of one-inch. The second tube welding unit was designed and built by NAA/LAD for use in this program, and was suitable for joining tubing up to three inches in diameter. This larger welding unit has been used satisfactorily to weld tubing sizes from 3/4 inch diameter to as large as three inches in diameter. Adapters have been designed which will permit this tool to weld tubing sizes as small as 1/8 inch in diameter. The first welding unit, set up for welding 1/8 inch diameter tubing, is shown in Figure 10. The second welding unit is shown in Figure 11.

These tools are operated by a Boston ring gear driven by a variable speed motor through a flexible cable and a pinion gear shown in Figure 12. A tungsten electrode is mounted in the ring gear and travels around the circumference of the tube as the gear rotates. The tube to be welded is located in the tool by transite inserts which are machined to fit the

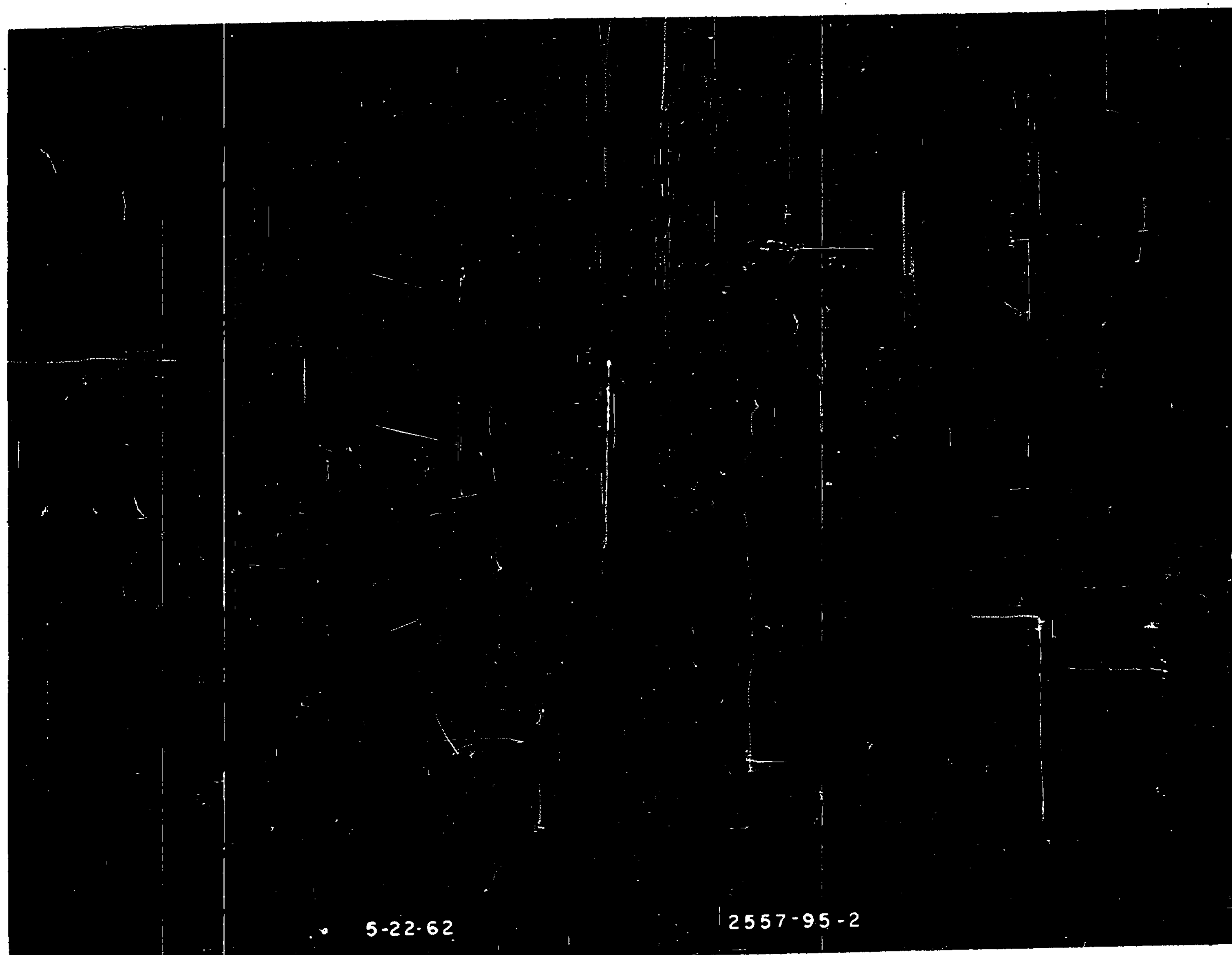
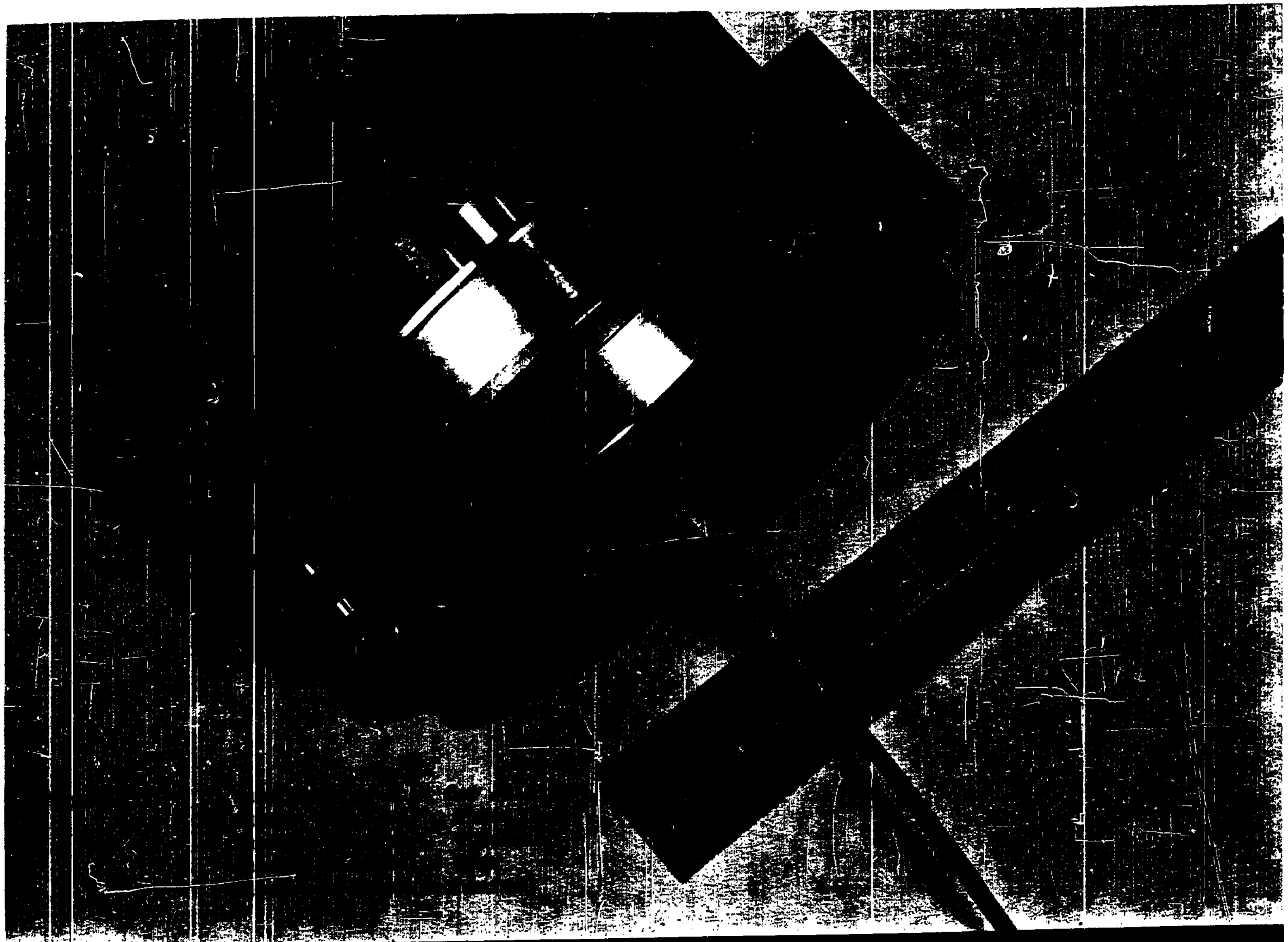


Figure 10 321 Welded Tubing, 1/8 Inch O.D., .030 Inch Wall Welded with Automatic TIG Tube Welder

Tube Welding Unit for Joining Tubing Sizes Up to Three Inch Maximum Diameter.
(Partially Disassembled View Shows Tool with Electrode in Overhead Welding Position and Transite Inserts for Positioning Tube and Closing Ends of Plenum Chamber)



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outer diameter of the tube, as shown in Figure 11. Any tube which has a diameter of three inches or less can be welded with this tool by use of a ring gear with a suitable size electrode and shielding gas cup and an appropriate set of transite inserts. These inserts also serve as end seals of a plenum chamber to contain the inert gas atmosphere around the weld joint area. The tool itself thus protects the joint area from the elements when used for "in place" tube joining on launch stands and in the field.

A Vickers 200 ampere, direct current, rectifier type power supply was employed for all welding. The controls for weld power, drive motor speed, and shielding gas flow are all mounted in a portable control box for convenient remote "in place" welding. This control box is shown in Figure 13. The latter Figure shows a tooling set-up for remote "in place" tube welding.

Phase II Tooling

The test joints in 1/4 and one inch diameter AM 350 and the one inch diameter Type 347 stainless steel tubing and the 1/8 inch diameter Rene' 41 alloy tubing welded qualification test specimens were made using the two welding tools described above. An external fitted sleeve was used with all of these joints except the one inch AM 350 stainless steel tubing specimens. The sleeves served to align the tube ends to be welded and supplied the filler metal required to prevent excessive concavity in the weld bead. The one inch diameter AM 350 stainless steel tubing joints did not require the use of sleeves because of the greater wall thickness of this tubing, as discussed on page 69.

The three inch diameter Type 347 stainless steel tubing welded joint specimens for qualification testing were welded with a third set of tools. This set of tools had been developed and built by NAA/LAD as part of a previous program. The set consisted of both an external and an internal tube welder, which are shown in Figures 14 and 15. The welding parameters for these tools are discussed on page 69 and are shown in Table X.

The first two types of welding units described above required an "in place" supply of filler metal in the form of an external sleeve. These tools were found to be unsatisfactory for welding aluminum tube joints. Work was begun on a new type of welding unit which would provide for the continuous addition of filler material during welding of a tube joint. A "bread board" model of such a tool was designed, built and used to demonstrate the feasibility of the tooling concept and, also, was used to join the one inch diameter aluminum alloy qualificaton test specimens. The filler material is added automatically in the form of wire by means of a set of rollers driven by a variable speed, direct current electric motor. The "bread board" tool assembly incorporating the wire feed mechanism and the tungsten electrode inert gas shielded (TIG) welding torch is clamped on the tube near the end where the weld joint is to be made. The clamping mechanism also permits the two components, the torch and the feed mechanism, to be driven as a unit around the tube circumference by an additional

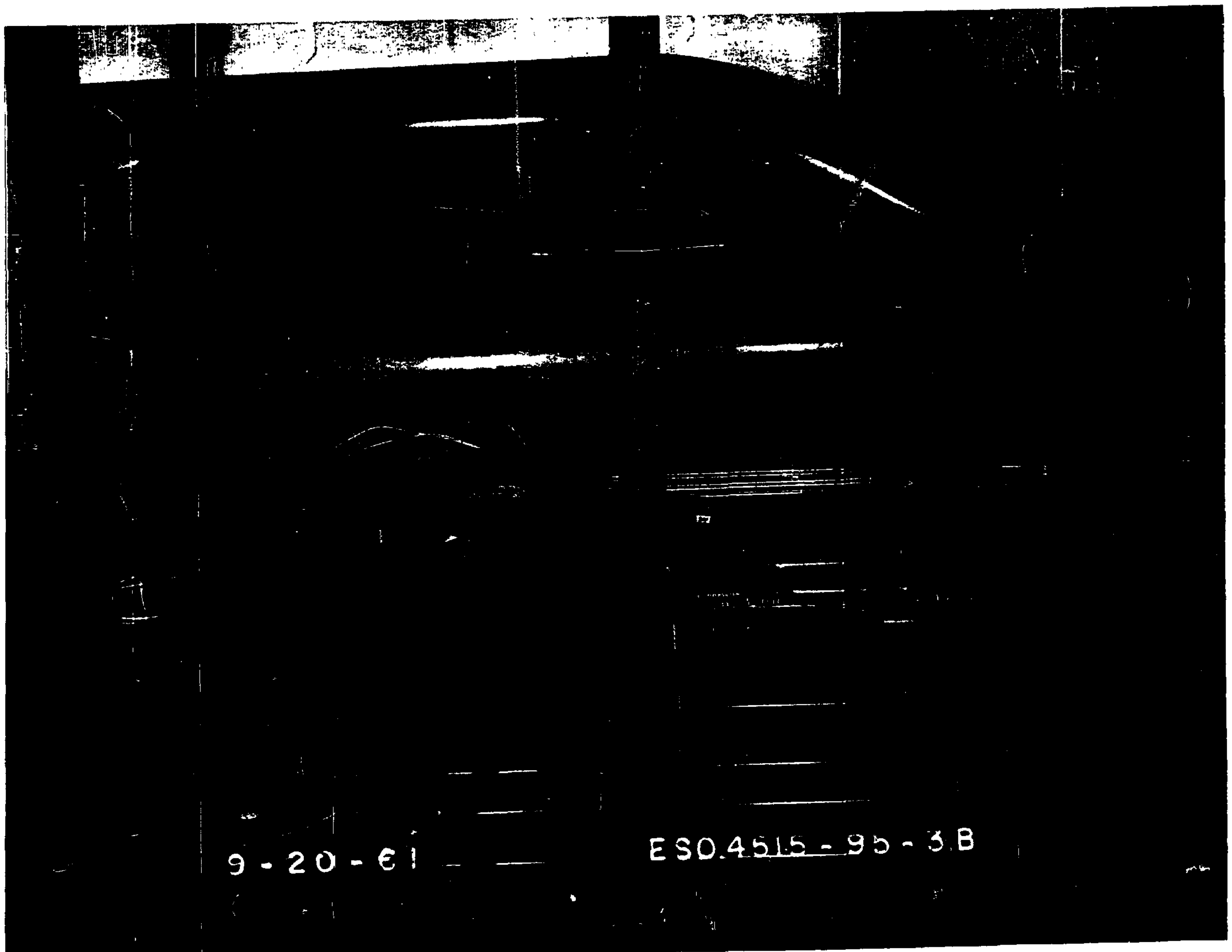


Figure 13. Tube Welding Unit Set Up for Joining One-Inch Diameter Tubing in Area of Limited Access.

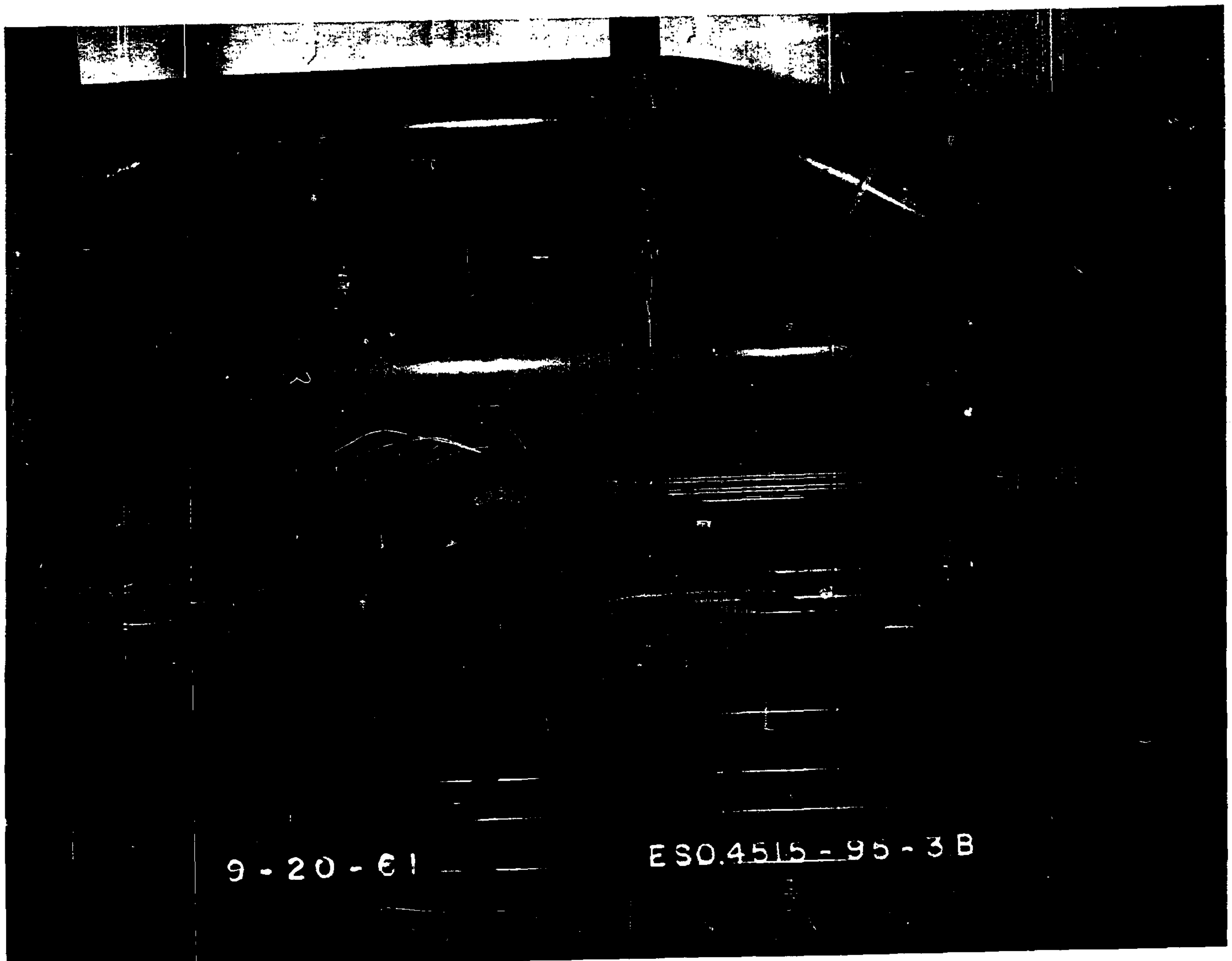


Figure 13. Tube Welding Unit Set Up for Joining One-Inch Diameter Tubing in Area of Limited Access.

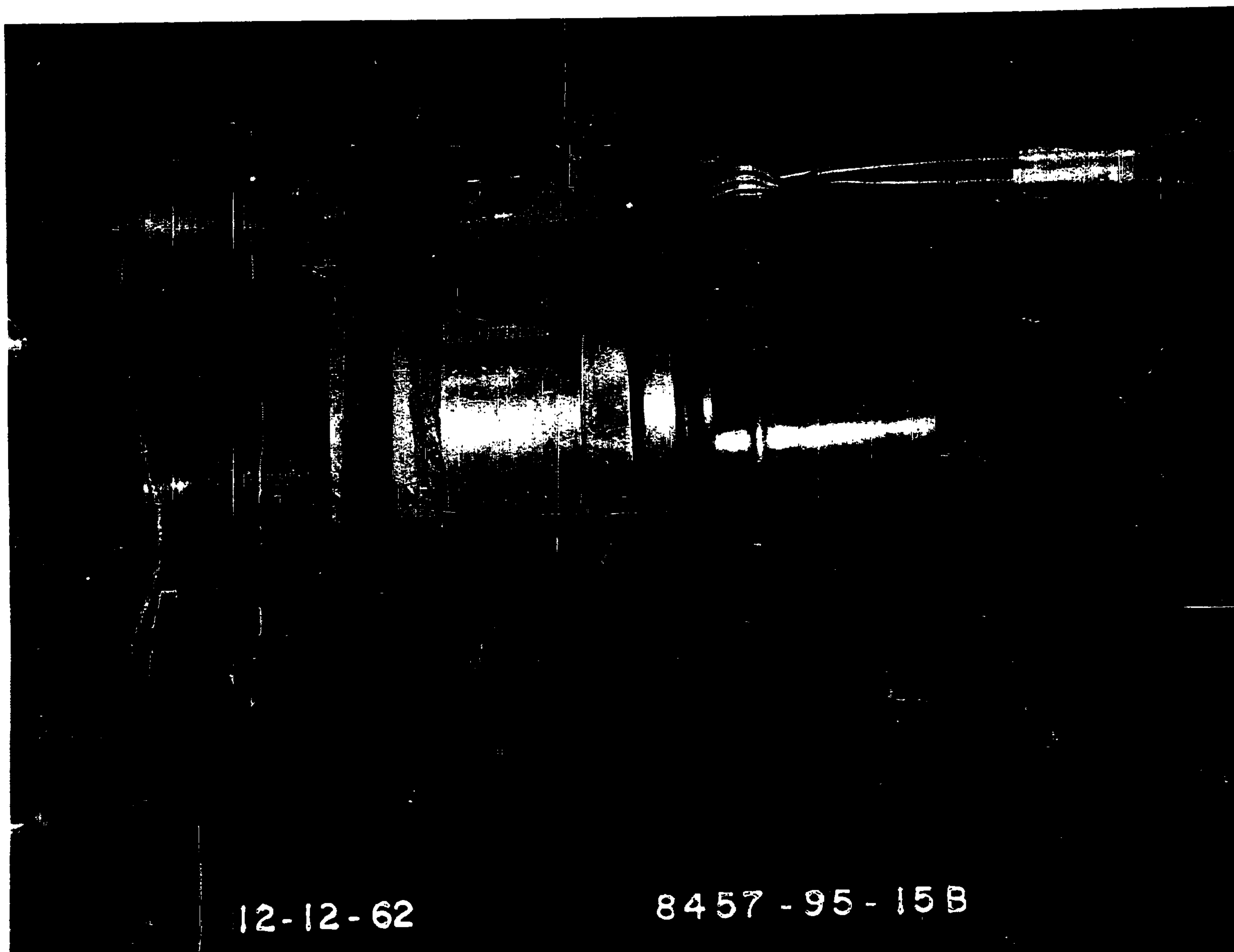


Figure 34. External Tube Welding Tool

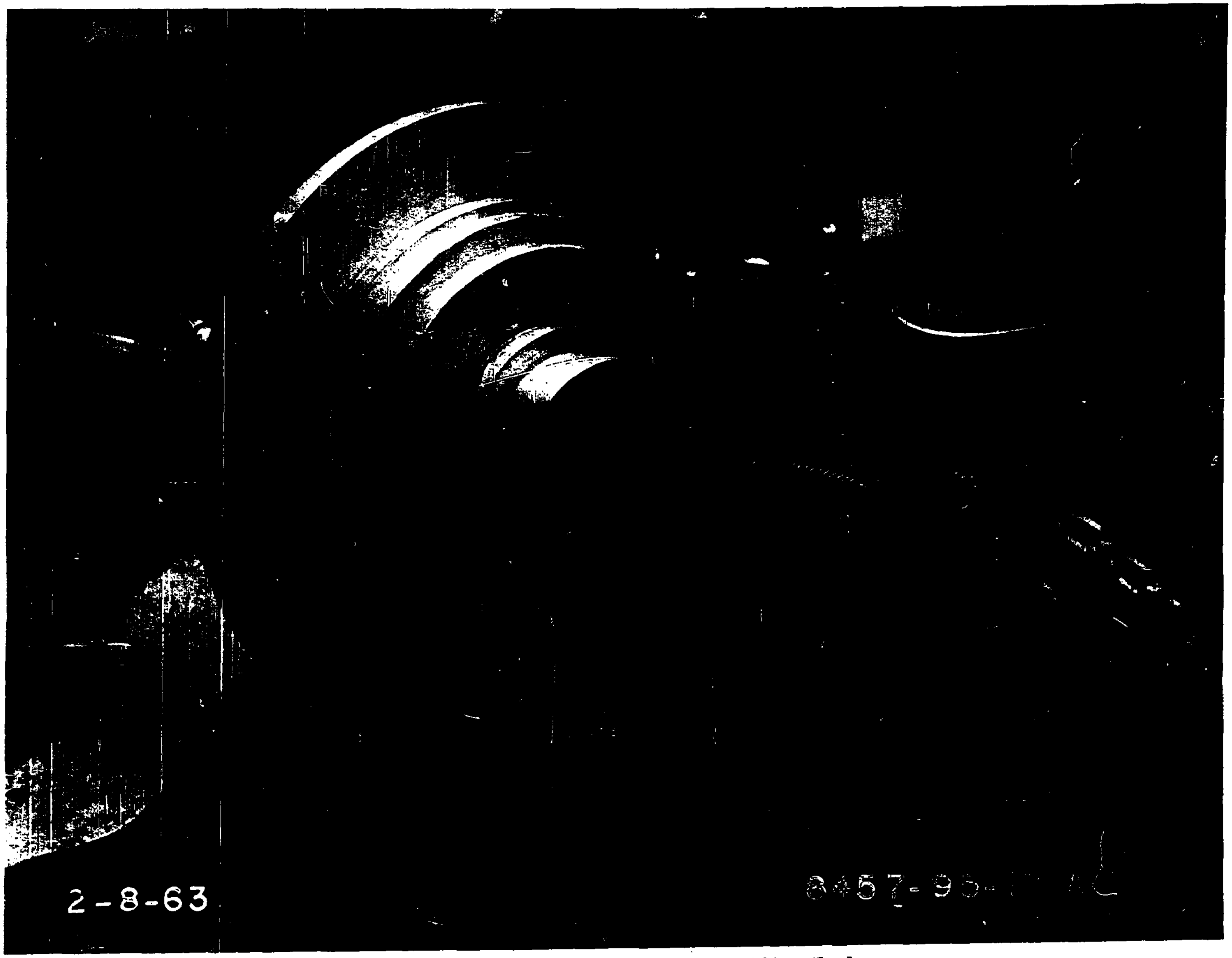


Figure 15. Internal Tube Welding Tool

TABLE X. WELD PARAMETERS FOR JOINING TUBING FOR USE IN ROCKET PROPULSION F

TUBING SYSTEM MATERIAL	TUBE SIZE (inches) OD	WALL	SLEEVE THICKNESS (inches)	WELD TYPE AND NO. OF PASSES	DIAMETER OF ELECTRODE (a) (inches)	WELD CURRENT (amperes)	ARC VOLTAGE (volts)	TRAVEL SPEED (Seconds per Revolution)
AISI Type 347 Stainless Steel	1	.083	.030	External 1 pass	3/32	84	10.0	26.5
	3	.250	None	Internal 1 pass plus	3/32	100	9.5	180
				External 1 pass	3/32	110	9.5	210
AM 350 CRT Stainless Steel	1/4	.042	.015	External 1 pass	1/16	15 (c)	12.0	17
AM 350 SCT Stainless Steel	1	.134	None	External 1st pass 2nd pass	3/32	95 55	14.0 14.0	45 45
Rene' 41 Alloy	1/8	.010	.010	External 1 pass	1/16	5 (c)	18.0	8.5
	1	.065	.031 (d)	External 1 pass (d)	1/16	52	15.0	27
6061-T6 Aluminum	1	.058	.045 Diam. 4043 Alum. Alloy Wire	External Wire Feed (e)	1/16	26 (f)	13.0	48

Notes:
(a) All welds made with two percent thoriated electrodes.
(b) Number denotes electrode position in terms of hour positions of clock; electrode otherwise noted.
(c) Electrode travel started before weld current initiated.
(d) Weld schedule and joint type are for preliminary weld specimens. Final weld sche inch diameter Rene' 41 tubing discontinued because of rejection of tubing.
(e) Wire feed was at rate of 12 inches per minute for electrode traveling speed of 4
(f) Current of 20 amperes was used to preheat start area for 20 seconds, current was which electrode travel and wire feed were started within five seconds. Approxima current was reduced to compensate for effect of preheating ahead of electrode. A feed was sloped off, then weld current was sloped off to zero by the time approxi
(g) Solar 202 flux was also used on inside surfaces of tube and joint at joint area.

PARAMETERS FOR JOINING TUBING FOR USE IN ROCKET PROPULSION FLUID SYSTEMS

WELD TYPE AND NO. OF PASSES	DIAMETER OF ELECTRODE (a) (inches)	WELD CURRENT (amperes)	ARC VOLTAGE (volts)	TRAVEL SPEED (Seconds per Revolution)	WELDING START POSITION	SHIELDING GAS AND FLOW RATE		PURGE TIME (minutes)
						TORCH	BACKUP	
External 1 pass	3/32	84	10.0	26.5	6 (b)	75% Argon 25% Helium 20 c.f.h.	Helium 40 c.f.h.	5
Internal 1 pass plus	3/32	100	9.5	180	6	75% Argon 25% Helium 50 c.f.h.	Helium 50 c.f.h.	1
External 1 pass	3/32	110	9.5	210	12	75% Argon 25% Helium 60 c.f.h.	Helium 40 c.f.h.	3
External 1 pass	1/16	15 (c)	12.0	17	Traveling	75% Argon 25% Helium 20 c.f.h.	Helium 50 c.f.h.	10
External 1st pass 2nd pass	3/32	95 55	14.0 14.0	45 45	7:30	75% Argon 25% Helium 40 c.f.h.	Helium 50 c.f.h.	15
External 1 pass	1/16	5 (c)	18.0	8.5	Traveling	75% Argon 25% Helium 15 c.f.h.	Helium 30 c.f.h.	10
External 1 pass (d)	1/16	52	15.0	27	9	75% Argon 25% Helium 35 c.f.h.	Helium 10 c.f.h.	15
External Wire Feed (e)	1/16	26 (f)	13.0	48	11 (e)(f)	Helium 50 c.f.h.	Argon 30 c.f.h. (g)	1

two percent thoriated electrodes.
trode position in terms of hour positions of clock; electrode travel clockwise direction unless

arted before weld current initiated.
oint type are for preliminary weld specimens. Final weld schedule and joint design work on one
41 tubing discontinued because of rejection of tubing.
e of 12 inches per minute for electrode traveling speed of 4 inches per minute counterclockwise travel.
s was used to preheat start area for 20 seconds, current was then increased to 26 amperes after
el and wire feed were started within five seconds. Approximately 2/3 around circumference weld
to compensate for effect of preheating ahead of electrode. After overlapping weld start, wire
then weld current was sloped off to zero by the time approximately 1/2 a revolution was made.
lso used on inside surfaces of tube and joint at joint area.

2

variable speed, direct current electric motor. A vee-belt drive connection was used initially, but it developed excessive slippage during the ckeck-out testing. The tool was reworked to incorporate a chain drive, shown in Figure 16, which supplied more positive drive and indexed the motion of the different units which made up the tool.

4.2 WELDING AISI TYPE 321 AND 347 STAINLESS STEEL TUBING

Preliminary weld parameters for joining Types 321 and 347 stainless steel tubing were established during the Phase I work. These parameters were developed using only Type 321 stainless steel tubing, which has welding properties similar to the Type 347 stainless steel tubing from which the Phase II qualification test specimens were later made. The Type 321 stainless steel tubing was available in NAA laboratory stock. The difference between the two materials, as shown in Table V, page 16 , is in the stabilizing elements used to prevent chromium depletion of the grain boundaries during welding and the consequent sensitization of the material to integranular attack and stress corrosion. No major differences in welding properties of the two materials were observed during this investigation. The welding characteristics of 1/8, 1 and 3 inch diameter sizes of Type 321 stainless steel tubing were investigated during the Phase I part of this program. The cleaning procedure for all of the welds made in the Type 321 stainless steel tubing consisted of preparing the surfaces to be welded by stainless steel wire brushing and cleaning with acetone immediately prior to welding. This cleaning procedure was adequate to produce a satisfactory weld. Welding procedures for the one inch and three inch diameter Type 347 stainless steel tubing were developed during Phase II, and the required qualification test specimens of this material were welded. The cleaning procedure used prior to welding the Type 347 stainless steel joints was the same as described above for the Type 321 stainless steel joints.

Welding 1/8 Inch Diameter Type 321 Stainless Steel Tubing

The 1/8 inch diameter 321 stainless steel tubing was welded using the tool and set up shown in Figure 10, page 43. Some difficulty was encountered in welding this 1/8 inch diameter by .012 inch wall thickness tubing due to the difficulty of initiating the arc at the required low current level of 2 to 3 amperes; but, by coating the electrode tip with graphite it was possible to initiate the arc consistently in this low range of welding current settings. The final weld schedule developed included the following procedures: the drive motor was started, the welding current was initiated at two to three amperes and manually increased to the level for welding, about 10 amperes. The weld was made in one revolution of the tool, after which the electrode travel speed was increased while the welding current level was manually decreased to zero. This was done to prevent crater cracking at the end of the weld bead. Argon inert gas shielding was used on the torch side and helium gas shielding was used on the back-up side of the weld. Filler metal was added to the weld by the melting down of the fitting sleeve, which was machined from Type 321 stainless steel rod. This sleeve fitting also served to align the tube

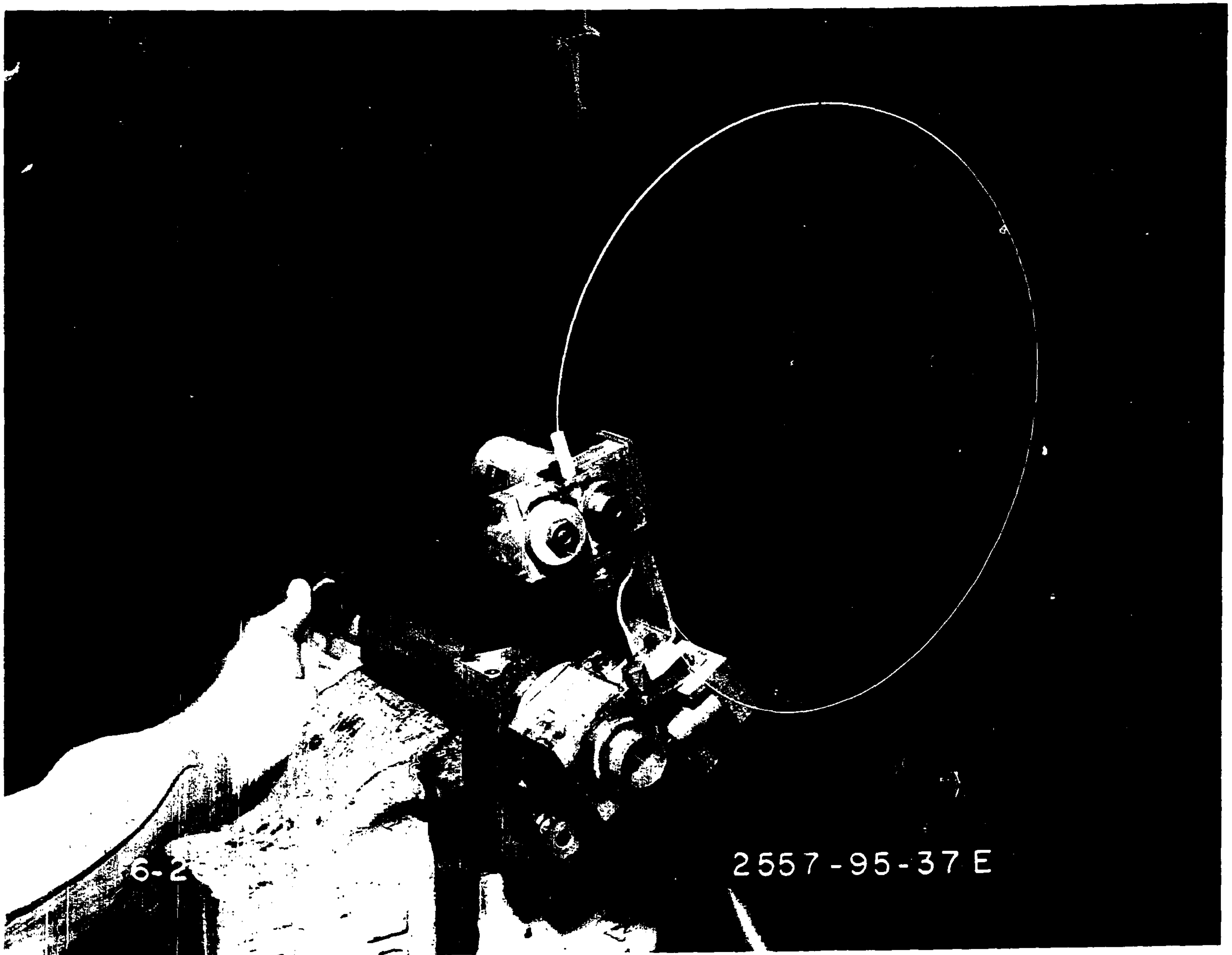


Figure 16. Aluminum Tube Welder and Wire Feed Mechanism

ends for the welding operation. Reproducible welds of good quality, as determined by visual examination, were made using this method in both the horizontal and vertical positions.

Welding One Inch Diameter Type 321 and 347 Stainless Steel Tubing

One inch diameter by .035 inch wall thickness Type 321 stainless steel tubing was welded using the three-inch diameter tube welding tool designed and constructed for this program. No difficulties were encountered with operation of the tool in regard to tube alignment, shielding gas coverage or mechanical operation of the tool. Welding schedules were developed for the one inch diameter Type 321 stainless steel tubing. These schedules included manual down-sloping (reduction) of the weld current and the increase of the travel speed after one revolution to eliminate crater cracking, similar to the 1/8 inch diameter tube welding schedule described in the preceding paragraph. Filler metal addition and tube end alignment were accomplished by use of a fitting sleeve. These fitting sleeves were made by expanding a section of the one inch diameter tubing and then finish machining the outside of the sleeve to the desired wall thickness. Argon shielding gas was used on the torch side and helium shielding gas on the back-up side of the weld. Radiographic and metallographic inspection showed that satisfactory welds were made in both the vertical and the horizontal positions.

After development of the final weld parameters, reproducible "blind" welds were then made with the operator watching only a stopwatch and the weld current ammeter. The effect of poor fit-up on the weld schedule and quality was determined by making a weld between two tubes separated by a 1/32 inch gap. This weld exhibited slight concavity, but this concavity did not extend into the tube wall.

The final weld schedule for joining the one inch diameter by 0.083 inch wall Type 347 stainless steel tubing qualification test specimens is presented in Table X. The general procedure employed was similar to that used in the above described work with Type 321 stainless steel tubing. A filler metal sleeve was expanded to the size required for a slip fit over the tubing, and was finish machined to the desired wall thickness. The sleeve was then slipped over the butted tube ends and the weld joint was made in a single pass. The quality of the joint was determined by visual and radiographic inspection. A preliminary one inch diameter Type 347 stainless steel burst specimen was welded and tested to failure at a temperature of 200 F. Failure occurred in the parent tube material parallel to the longitudinal axis of the tube, similar to the failure shown in Figure 36. A pressure of 12,800 psig was required to cause failure, which was considerably in excess of the 8000 psi burst pressure requirements. This value was in excellent agreement with a parent metal tubing specimen which failed in a similar manner under the same conditions at a pressure of 12,000 psig.

Based on the success of the preliminary burst test, the qualification test specimens for the one inch diameter Type 347 stainless steel tubing were welded and the welds were inspected visually and radiographically.

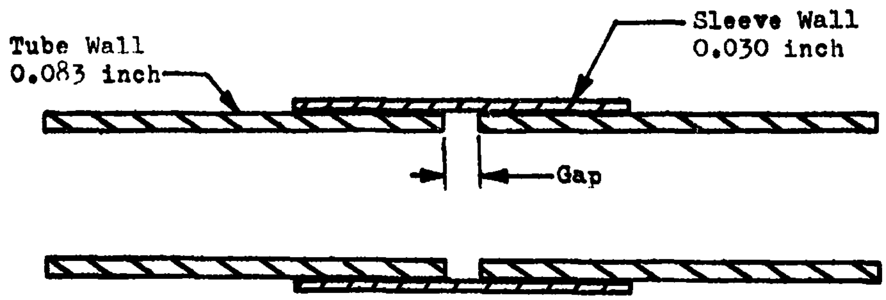
Following welding and inspection, the specimens were then cut to the required lengths for the burst, stress reversal bend, vibration, temperature shock and pressure impulse tests. End plugs were installed in the burst and stress reversal bend specimens. A total of 17 specimens of the one inch diameter by .083 inch wall Type 347 stainless steel were fabricated for qualification testing. Radiographic inspection of these specimens indicated good weld quality. These qualification test specimens successfully passed the proof pressure, leakage, burst, stress reversal bend, temperature shock, pressure impulse and vibration testing, as reported in Table XVIII of Section 6, page 137.

Additional specimens were welded with gaps or spaces between the butting ends of the tubes, and also with offset spacing of the sleeve with respect to the tubing. These specimens were prepared in order to determine the fit-up limitations of the weld joining process for the one inch diameter Type 347 stainless steel tubing. Five butt end gapped specimens were welded. One specimen had a gap width of 0.040 inch, two specimens had gaps of 0.060 inch width and two specimens had gaps of 0.080 inch width, as shown in Figure 17 (a). The 0.040 inch gap width specimen was welded satisfactorily. The 0.060 and 0.080 inch gap width specimens did not weld satisfactorily. The .040 inch wide gap could be satisfactorily welded because the gap closed up as a result of thermal expansion due to heating of the material ahead of the welding electrode. The specimens with the larger width gaps would not close up sufficiently, resulting in excessive penetration and concavity in the weld joint. Such joints would have reduced strength and the internal weld bead may be of sufficient size to restrict fluid flow and cause turbulence in the region of the joint. Therefore, .040 inch is recommended as the maximum gap width which can be tolerated with this wall thickness and tubing diameter for Type 347 stainless steel.

Four joint specimens of the one inch diameter Type 347 stainless steel tubing were successfully welded with the fitting sleeve offset from the tubing centerline. Two of these specimens were welded with the sleeve "ideally" offset from the tubing by a uniform circumferential gap of at least 0.0050 inch. These amounts of circumferential gap, or offset, were obtained by boring out the inner diameter of the fitting sleeves so that they were 0.005 and 0.010 inch oversize, respectively, as shown in Figure 17 (b).

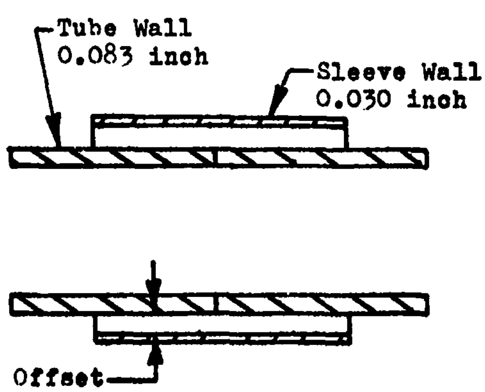
The actual offsets in these joints were probably closer to 0.005 and 0.010 inch, with all the gap probably being at the bottom side of the tube, as sketched in Figure 17 (c), since the sleeve was not tackwelded to the tubing. The procedure employed in welding these specimens was to commence welding at the bottom side of the tube in the area of maximum gap. A typical cross-section of one of the weld joints and a photograph of the bead drop-through surface are both shown in Figure 18.

Two methods of end closure were investigated to insure that failure of the burst or pressure impulse test specimens would not occur at the specimen ends. The most satisfactory method was to butt weld an 0.040

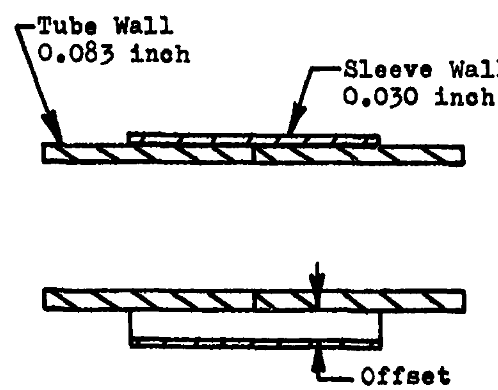


(a) GAPPED WELDING TEST JOINT

Gap Between Tube Ends	Gap Width (inches)	Concavity
a	0.040	OK
b	0.060	Excessive
c	0.080	Excessive



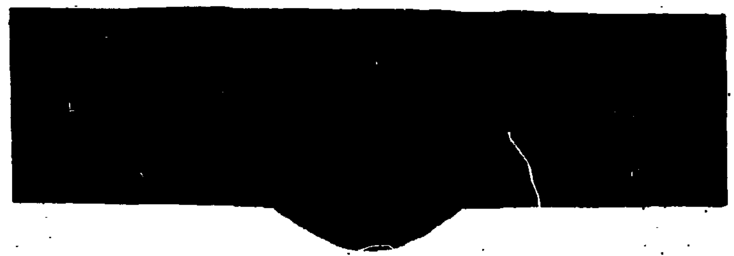
(b) TYPE "a" OFFSET



(c) TYPE "c" OFFSET

Offset Between Sleeve and Tube	Offset (inches)	Joint Quality
a1	0.0025	OK
a2	0.0050	OK
c1	0.0050	OK
c2	0.0100	OK

FIGURE 17
DETAILS OF OFFSET AND GAPPED WELDING TEST JOINT
FIT-UP LIMIT SPECIMENS FOR 1" O.D. x 0.083" WALL
TYPE 347 STAINLESS STEEL TUBE JOINING



(a) Cross-Section Through Weld Joint
Etchant: Kallings Reagent
Magnification: 10 X

(b) View of Weld Drop-Through Surface
Magnification: 10 X

Tube O.D.:	1 inch
Tube Wall Thickness:	0.083 inch
Sleeve Wall Thickness:	0.030 inch

Figure 18. WELDED JOINT IN 1" O.D. TYPE 347 STAINLESS STEEL TUBING

inch thick sleeve to the end plug and tube wall, as shown in Figure 19 (a). An alternate method which resulted in some bulging at the end fitting during the burst test was to internally fillet weld the end plug to the tube wall, as shown in Figure 19 (b).

Welding Three Inch Diameter Types 321 and 347 Stainless Steel Tubing

A limited number of welds were made in three inch diameter by .065 inch wall Type 321 stainless steel tubing during the Phase I part of the program. These welds were made using a procedure similar to that previously described for the one inch diameter by .065 inch wall Type 321 stainless steel tubing. The fitting sleeves were made by expanding lengths of the three inch diameter tubing. Some specimens were welded using argon gas as the shielding gas on the torch side of the welds. The other specimens were welded using as the shielding gas on the torch side of the welds a premixed bottled gas having the composition 75 percent argon and 25 percent helium.

Ovality of the "as received" tubing diameter caused some difficulty during welding because of joint offset resulting from tube end mismatch. In some areas the joint offset was calculated to be from .020 to .040 inches. During welding of some joints, this amount of offset resulted in the weld penetration moving to one side of the butt joint, which caused lack of fusion in the joint. However, several other specimens, which had as much as .030 inch mismatch, were able to be welded satisfactorily. The problem was eliminated by selectively matching the tube ends, without requiring the special sizing techniques that would be used in production operations.

Long weld times required for welding of the large diameter tubing caused a noticeable preheating effect from weld heat buildup which must be compensated for. When the weld was started at the 4 o'clock position, a heavy drop-through occurred when the weld reached the 12 o'clock position unless the welding current was reduced. This condition was alleviated by welding halfway around the tube, stopping to permit the joint area to cool, and then completing the weld.

The welding procedure for joining the .065 and .083 inch wall three inch diameter Type 321 stainless steel tubing described in the preceding paragraphs is not applicable for joining thick wall tubing or pipe, such as the 0.250 inch wall three inch diameter Type 347 stainless steel tubing to be used for the Phase II qualification test specimens. Extremely high welding currents would be required to make the joints in the 0.250 inch thick wall by single-pass welds. Such high currents would seriously decrease control of the weld puddle and would result in excessive drop-through of the weld bead.

An alternate method of weld joining heavy wall tubing and pipe had been developed previously by NAA. This method employs two weld passes without addition of filler wire. The first weld pass is made internally. This arrangement is sketched in Figure 21. Photographs of the tooling

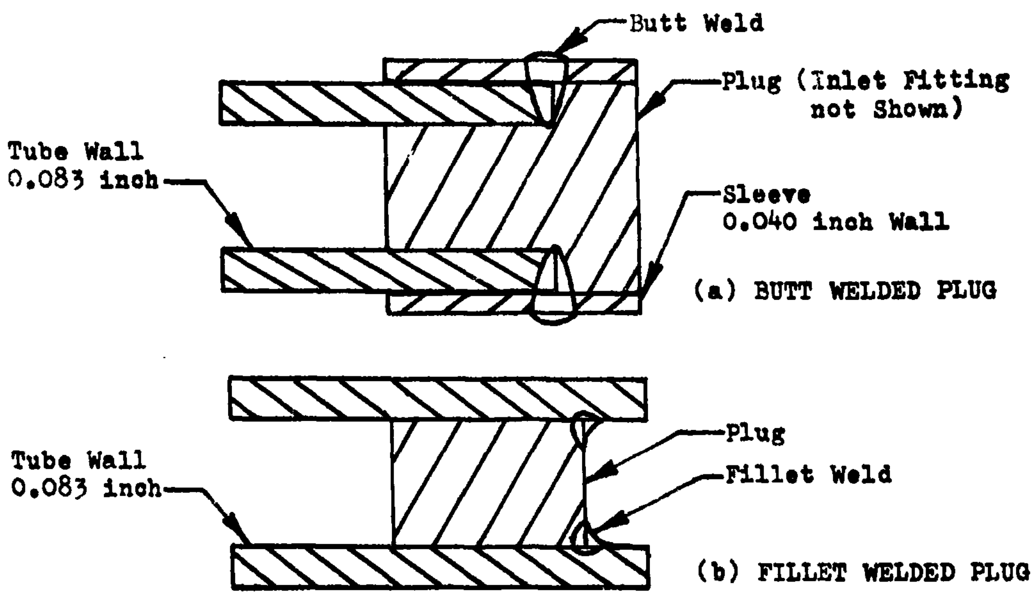


FIGURE 19
END PLUG CONFIGURATION FOR 1 INCH DIAMETER TYPE 347 AND AM 350 STAINLESS STEEL TUBING TEST SPECIMENS

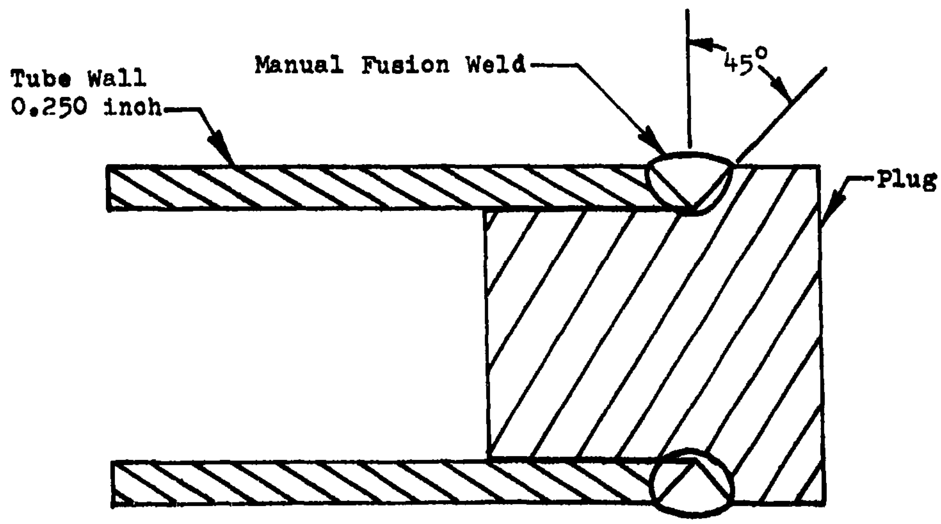


FIGURE 20
END PLUG CONFIGURATION FOR 3 INCH DIAMETER TYPE 347 STAINLESS STEEL TUBING TEST SPECIMENS

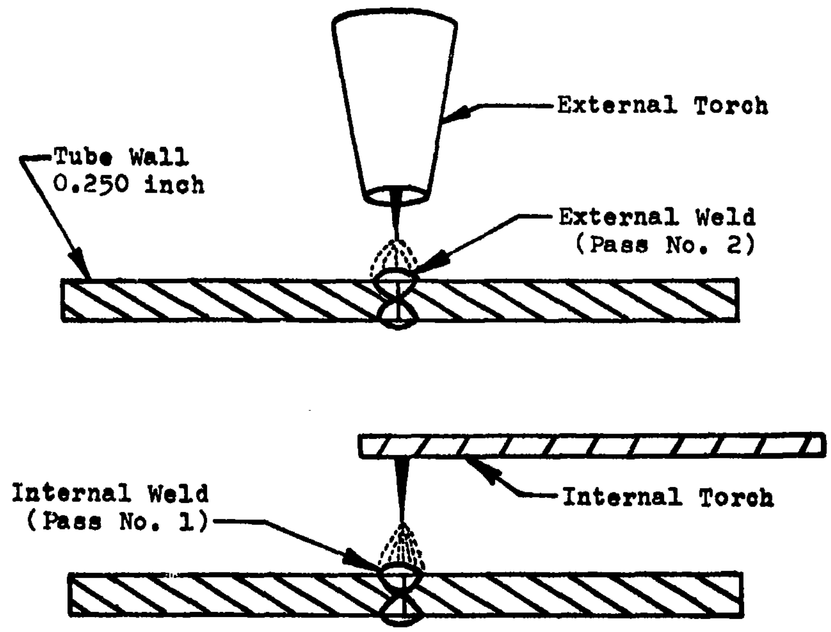
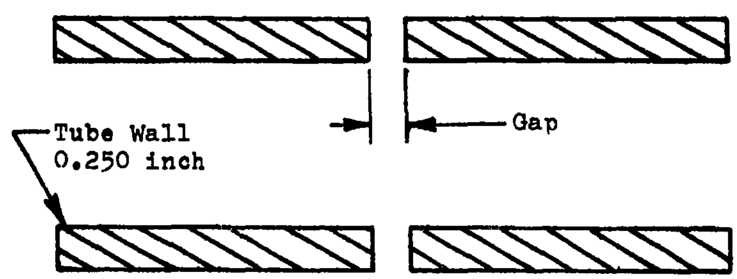


FIGURE 21
SCHEMATIC OF INTERNAL-EXTERNAL WELDING ARRANGEMENT



Gap Between Tube Ends	Gap Width (inches)	Concavity
a	0.040	OK
b	0.060	Excessive
c	0.080	Excessive

FIGURE 22
DETAILS OF GAPPED WELDING TEST OF 3 INCH
DIAMETER TYPE 347 STAINLESS STEEL TUBE JOINING

employed are shown in Figures 14 and 15, pages 48 and 49. This alternate procedure was used to weld the three inch diameter by 0.250 inch wall Type 347 stainless steel tubing. The quality of the weld joints was determined by visual and radiographic inspection of the joints after each of the two weld passes. The final weld schedule is shown in Table X, page 50.

A preliminary burst specimen of the three inch diameter by 0.250 inch wall Type 347 stainless steel tubing was welded and pressure tested to failure at 200 F. Failure occurred in the parent tube material parallel to the longitudinal axis of the tube at a pressure of 12,600 psig, which was considerably in excess of the 8000 psi burst pressure requirement. The failed specimen is shown in Figure 23. The qualification test specimens for the three inch diameter by 0.250 inch wall Type 347 stainless steel tubing were then welded, inspected visually and radiographically, and fitted with end plugs. The end plugs were manually fusion welded in place, as shown in Figure 20. The qualification test specimens successfully passed proof pressure, leakage, burst, and stress reversal bend testing.

A total of seven of the three inch diameter by 0.250 inch wall Type 347 stainless steel tubing test specimens were fabricated. Radiographic inspection of these specimens indicated good quality welds. One of the stress reversal bend specimens which was tested is shown in Figure 24.

The effect of a gap at the butting joint was determined for the three inch diameter by 0.250 inch wall Type 347 stainless steel tubing. Details of the gaps tested are noted in the sketch shown in Figure 22. It was determined that the maximum gap at the butting edges which could be tolerated was 0.040 inch. Gaps of 0.060 and 0.080 inch caused excessive concavity in the internal weld. This result is the same as that obtained for the one inch diameter tube joints where a fitting sleeve was used. A cross-section of one of the welds, and photographs of both the internal and external weld surfaces are shown in Figure 25.

4.3 WELDING AM 350 STAINLESS STEEL TUBING

General

Welding parameter development work for the AM 350 stainless steel tubing joints was not performed during the initial part of this program. The techniques for joining the particular sizes of tubing for the AM 350 stainless steel qualification test specimens were established during Phase II for 1/4 inch diameter by 0.042 inch wall AM 350 CRT tubing and for one inch diameter by 0.134 inch wall AM 350 SCT tubing. The 1/4 inch diameter AM 350 tubing was procured in the CRT (cold reduced and tempered) condition. The one inch diameter AM 350 SCT tubing was manufactured by gun drilling from bar stock. This tubing was procured in the annealed (solution treated) condition, and was heat treated to the SCT 900 (subzero cooled and tempered at 900 F) condition prior to weld joining. The cleaning procedure used prior to welding the AM 350 stainless steel joints was the same as the procedure for cleaning the Type 321 and Type 347 stainless steel joints. The surfaces to be welded were prepared by stainless steel wire brushing and cleaning with acetone immediately prior to welding.

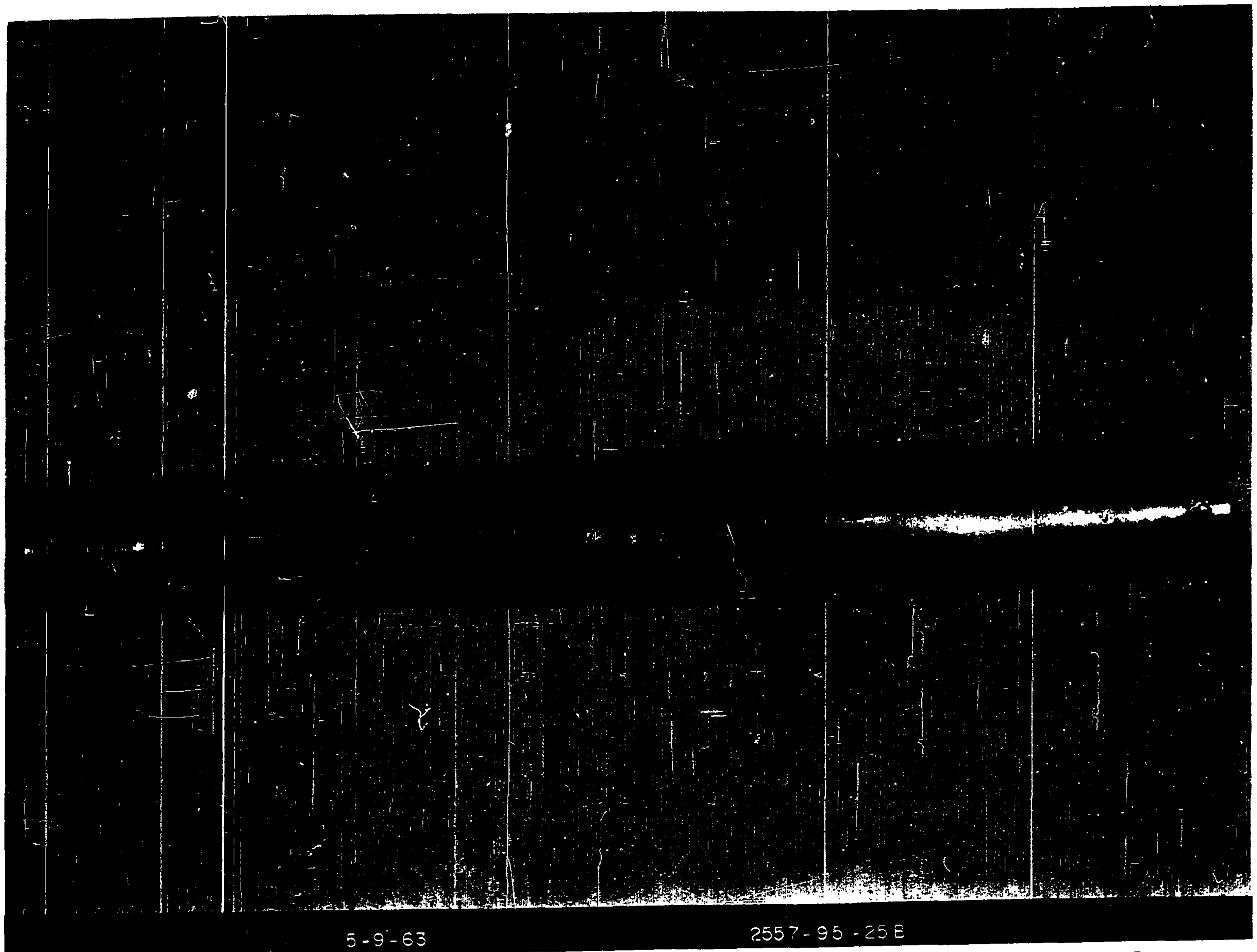


Figure 23. AISI Type 347 Stainless Steel Welded Tube Joint Burst Test Specimen Showing Rupture

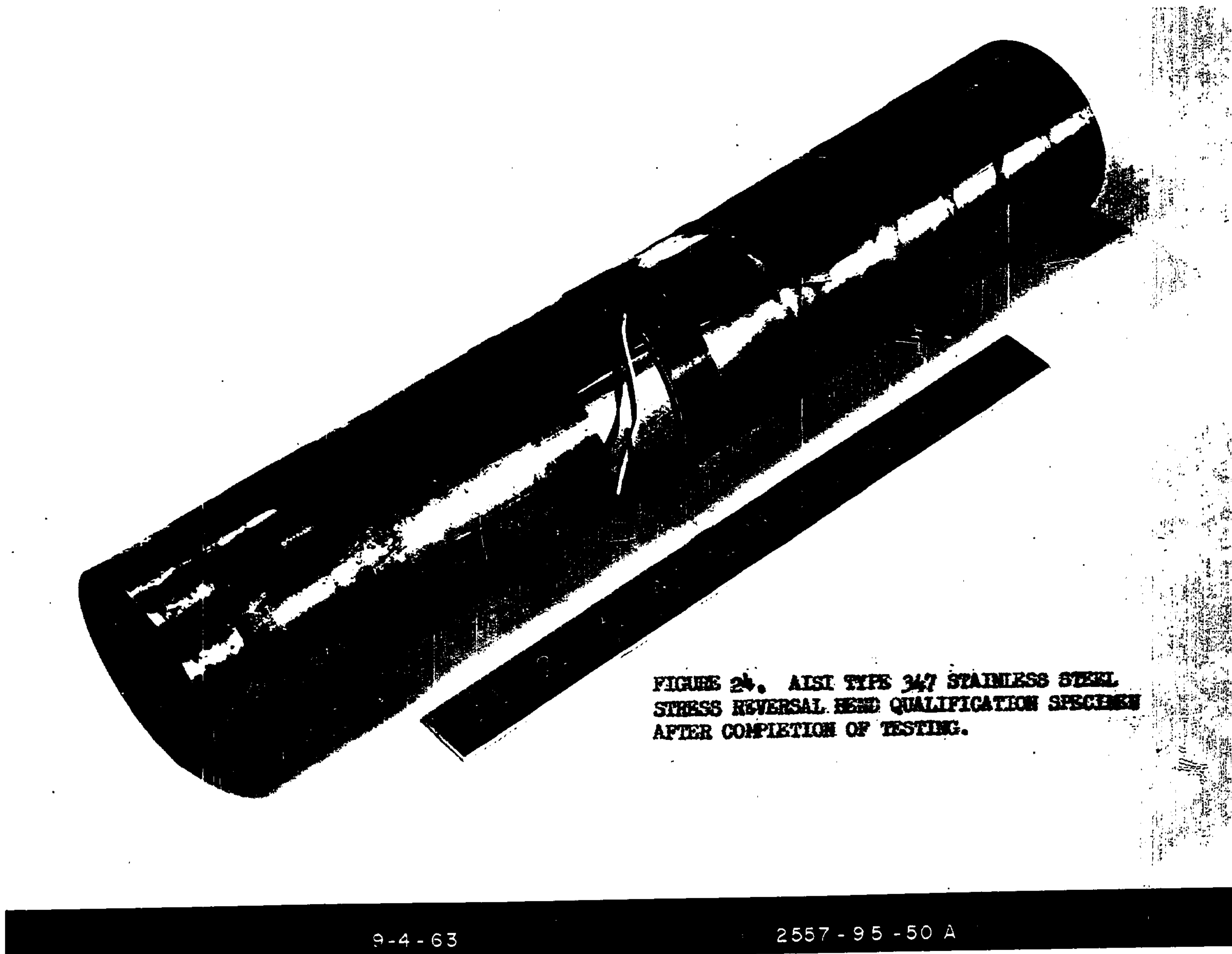
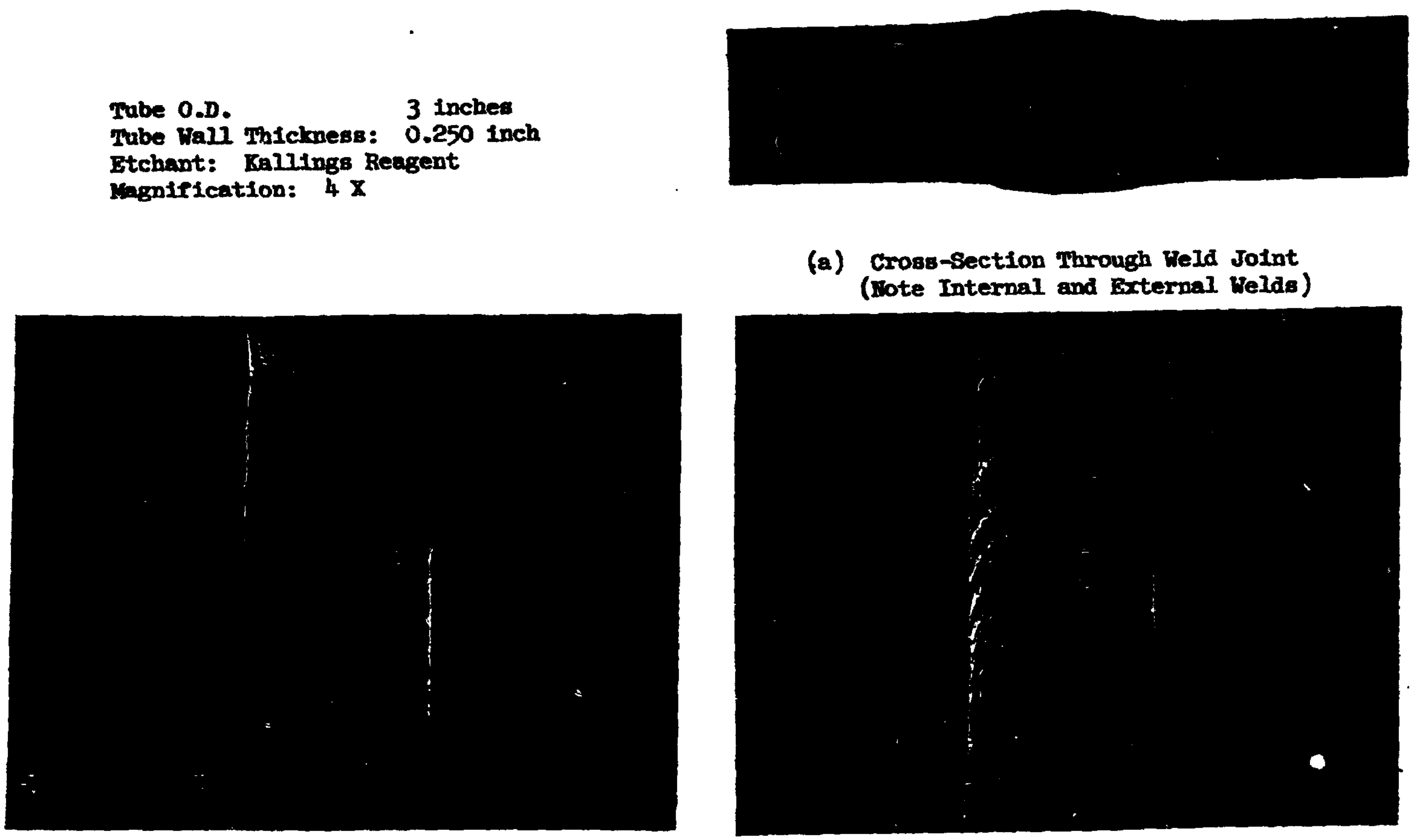


FIGURE 24. AISI TYPE 347 STAINLESS STEEL STRESS REVERSAL BEND QUALIFICATION SPECIMEN AFTER COMPLETION OF TESTING.

Tube O.D. 3 inches
Tube Wall Thickness: 0.250 inch
Etchant: Kallings Reagent
Magnification: 4 X



(a) Cross-Section Through Weld Joint (Note Internal and External Welds)

(b) View of Outer Surface Weld Bead

(c) View of Inner Surface Weld Bead

Figure 25. WELDED JOINT IN 3" O.D. TYPE 347 STAINLESS STEEL TUBING

Welding 1/4 Inch Diameter AM 350 CRT Stainless Steel Tubing

A final weld schedule, as shown in Table X, page 50, was developed for joining the 1/4 inch diameter by .042 inch wall AM 350 CRT stainless steel tubing. The procedure employed for welding this tubing included the use of an external fitting sleeve which was machined from AM 355 stainless steel bar stock. The welding procedure was generally similar to that previously described for the one inch diameter by .083 inch wall Type 347 stainless steel tubing.

The preliminary welded joint burst test specimens for the 1/4 inch diameter AM 350 CRT stainless steel tubing successfully passed the required proof pressure and leakage tests at 600 F, and did not rupture when subjected to the required burst pressure of 20,000 psig. The remaining 1/4 inch diameter AM 350 CRT stainless steel tube specimens for qualification testing were then welded, inspected visually and radiographically, and fitted with end plugs. The end plug design is shown in Figure 26 for a typical specimen. All of these specimens were found to be suitable for use.

The weld joint qualification specimens successfully passed the proof pressure, leakage, and burst tests, and the stress reversal bend test at -320 F. The one stress reversal bend specimen tested at 600 F failed after completing 91,800 cycles of a required 200,000 cycles at a maximum bending stress of 32,600 psi at the joint centerline. Examination of the fracture in this specimen showed that fatigue failure of the tubing had occurred in the weld heat-affected zone directly adjacent to the fusion zone, Figures 27 and 28.

Welding One Inch Diameter AM 350 SCT Stainless Steel Tubing

The one inch diameter by 0.134 wall thickness AM 350 stainless steel tubing was manufactured by gun barrel drilling from annealed bar stock. This material required heat treatment to the SCT condition to develop the required strength properties. In order to determine the heat treatment to be used, a chemical analysis was conducted to assure that the material was AM 350 and not AM 355 stainless steel. The results of the analysis showed that the material was AM 350. The analysis is presented in Table XI. The material was then heat treated to the SCT condition, as follows:

Solution Treatment:	Heat at 1710 F for a minimum time at temperature of fifteen (15) minutes. Air Cool to room temperature.
Sub-zero Treat:	Hold at -100 F for three (3) hours.
Aging Treatment:	Heat at 900 F for three (3) hours; Air Cool.

Following heat treatment, and prior to welding, the heat treated tubing surfaces were vapor honed to ensure complete removal of any heat treat scale, although this procedure would not be required for ordinary production or field repair work.

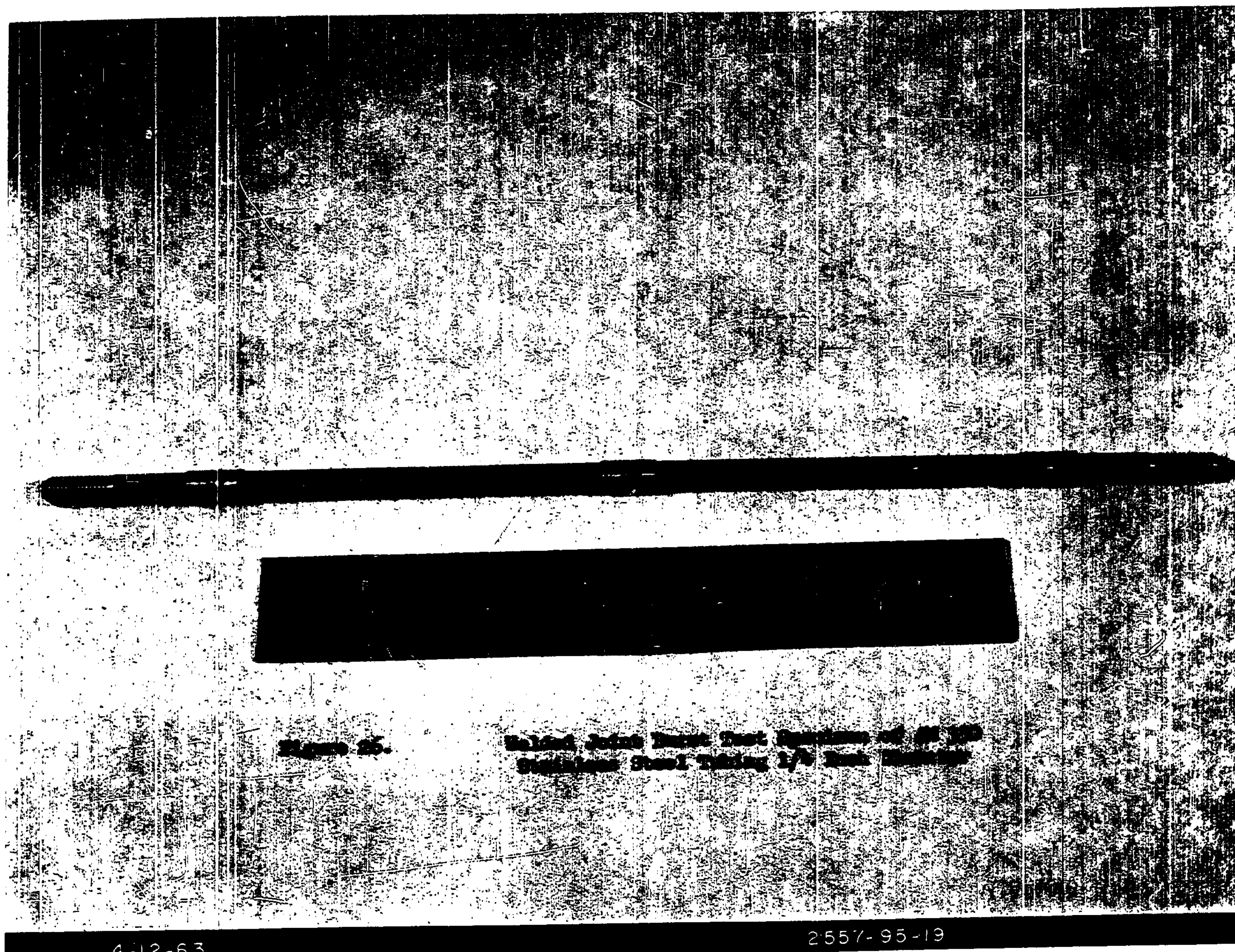


Figure 25. Welded Joint Burst Test Specimen of [illegible] Stainless Steel Tubing 1/4 [illegible] [illegible]

FIGURE 27. HEAT AFFECTED ZONE FAILURE IN WELDED JOINT SPECIMEN OF AM 350 CRT 1/4 INCH DIAMETER STAINLESS STEEL TUBING TESTED IN STRESS REVERSAL BENDING AT 600 F.

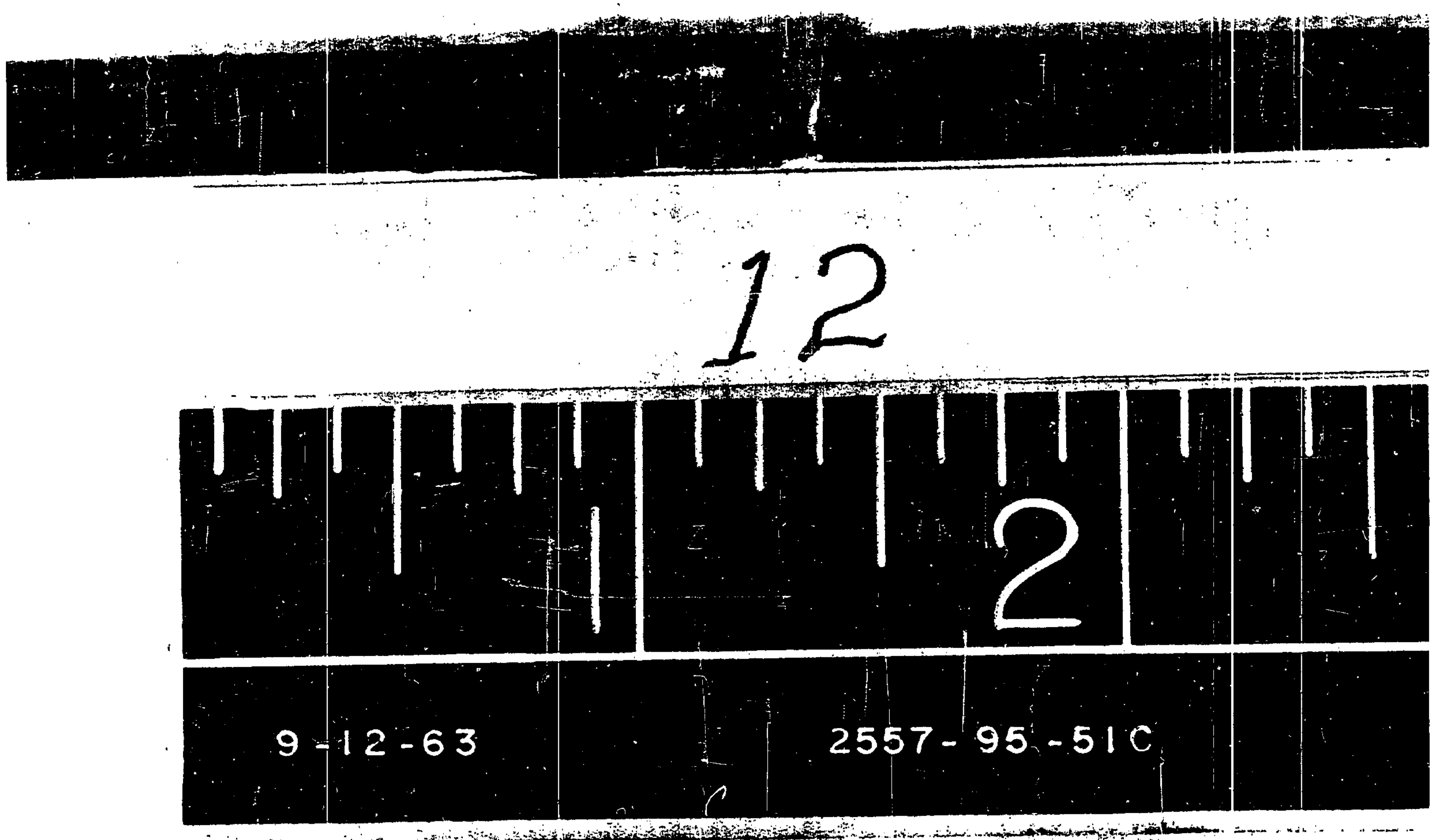


FIGURE 26. FRACTURE SURFACES SHOWING FATIGUE FAILURE MARKINGS. WELDED JOINT SPECIMEN OF 1/4 INCH DIAMETER AM 350 CRT STAINLESS STEEL TUBING TESTED IN STRESS REVERSAL BENDING AT 600 F.

TABLE XI.
DETERMINATION OF MATERIAL OF
GUN-DRILLED 1" OD STAINLESS STEEL TUBING

Element	NAA Analysis of 1" OD x .134" wall AM 350 Tubing (percent)	Specification Composition (percent)	
		AM 350	AM 355
Carbon	0.10	0.08 - 0.12	0.10 - 0.15
Manganese	0.85	0.50 - 1.25	0.50 - 1.25
Silicon	0.23	0.50 max.	0.50 max.
Chromium	16.12	16.00 - 17.00	15.00 - 16.00
Nickel	4.28	4.00 - 5.00	4.00 - 5.00
Molybdenum	2.51	2.50 - 3.25	2.50 - 3.25
Nitrogen	(did not check)	0.07 - 0.13	0.07 - 0.13

A final weld schedule was developed for the one inch diameter by 0.134 inch wall AM 350 stainless steel tubing. This weld schedule is shown in Table X, page 50. Two joint designes were investigated for this tubing. One joint design used a fitted sleeve, as shown in Figure 29. The other joint design was a simple fusion butt weld made without the addition of filler material and welded in a single pass from the outside of the tube. Both of these joint configurations successfully passed the proof pressure, leakage and burst test requirements. The simple fusion butt weld joint design shown in Figure 30, which eliminated the requirement for the use of the sleeve, was selected for fabrication of the qualification test specimens. This choice was made on the basis of economy and weld schedule reproducibility. The high energy imputs required for the 0.134 inch wall tubing caused expansion of the sleeve. This sleeve expansion created a gap between the sleeve and the tube, which decreased the weld quality and reproducibility.

The specimens for the qualification tests of the one inch diameter AM 350 SCT stainless steel tubing were welded, inspected visually and radiographically, and found to be satisfactory. The end plug design for these specimens is sketched in Figure 24, page 62, and typical installed end plugs are shown in Figure 30. Sixteen welded joint specimens were fabricated, including the sleeve type joint preliminary burst test specimen. A total of five of these specimens were found by radiographic testing to be defective and to require rework. Of these specimens, two had to be completely rewelded due to porosity, lack of fusion, and excessive concavity. Two of the remaining specimens had both porosity and lack of fusion, and the last of the five specimens had only porosity. These three specimens were repaired by making a second weld pass over the original weld. The lack of fusion present in the welds indicated that the original weld schedule when these specimens were welded probably used slightly less current than was necessary to produce completely sound, defect-free welds.

The weld joint qualification specimens for the one inch diameter by .134 inch wall AM 350 SCT stainless steel tubing successfully passed the proof pressure, leakage, burst, stress reversal bend at -320 F, thermal shock, pressure impulse, and vibration tests. The one stress reversal bend specimen tested at 600 F failed after a life of somewhere between 94,000 and 183,000 cycles at a bending stress of 34,000 psi at the joint. Examination of the fracture surfaces of this specimen indicated that fatigue failure of the tube occurred in the weld heat-affected zone directly adjacent to the fusion zone. These fracture surfaces are shown in Figures 31 and 32.

The effect of fit-up of the butting ends of the tubes to be joined on the resultant weld quality was determined by welding specimens which had gaps of .020, .030, .040, and .060 inch widths between the tube ends. The maximum weld concavity measured was .015 inch for the gaps of .020 and .030 inch width, .040 inch maximum concavity for the .040 inch gap width, and .085 inch maximum concavity for the .060 inch gap width. Therefore, .030 inch (1/32 inch) is recommended as the maximum gap width which can be tolerated with this wall thickness and tubing diameter for AM 350 stainless steel.

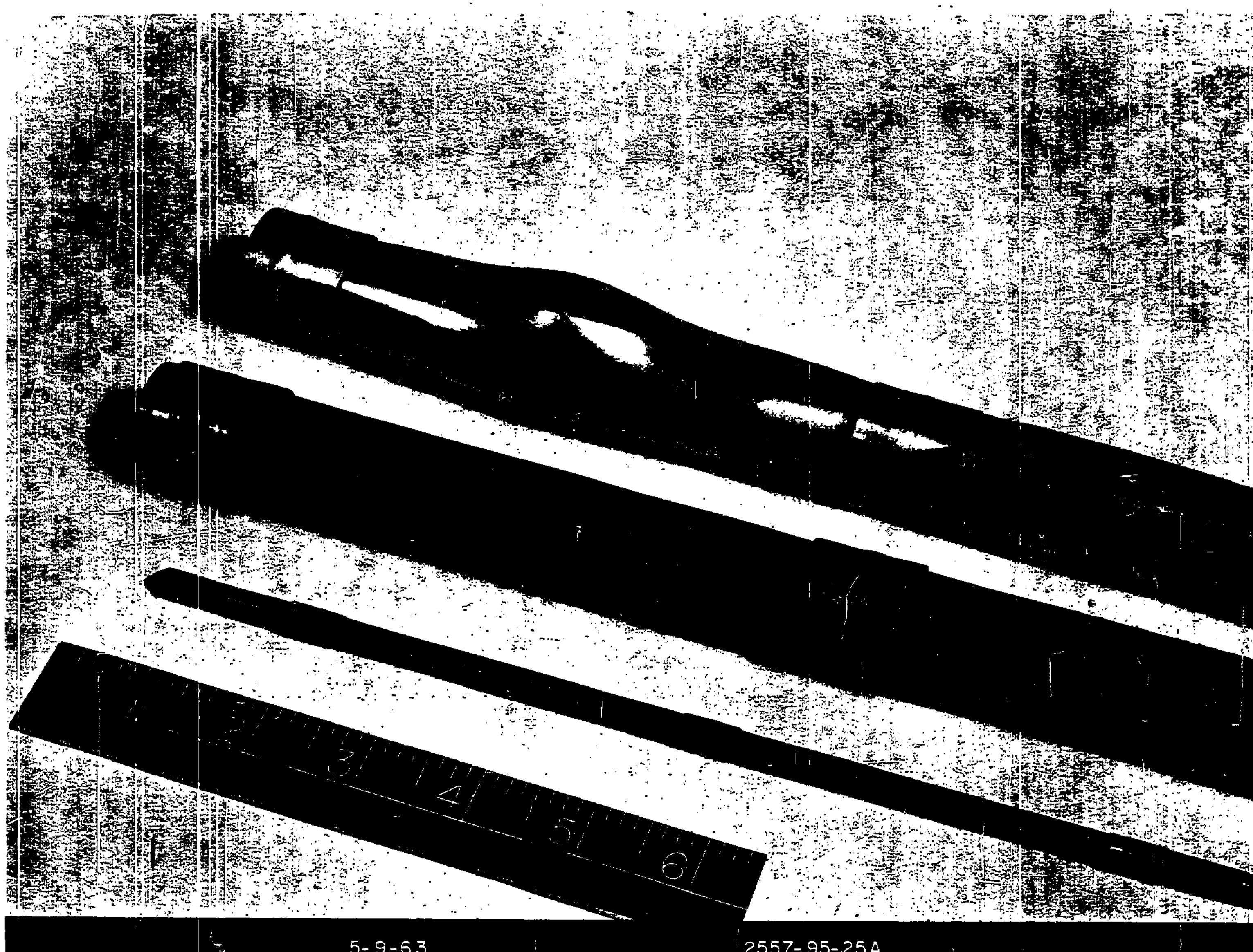


Figure 29. AISI Type 347 and AM 350 Stainless Steel Sleeve Joint Welded Specimens After Burst Test

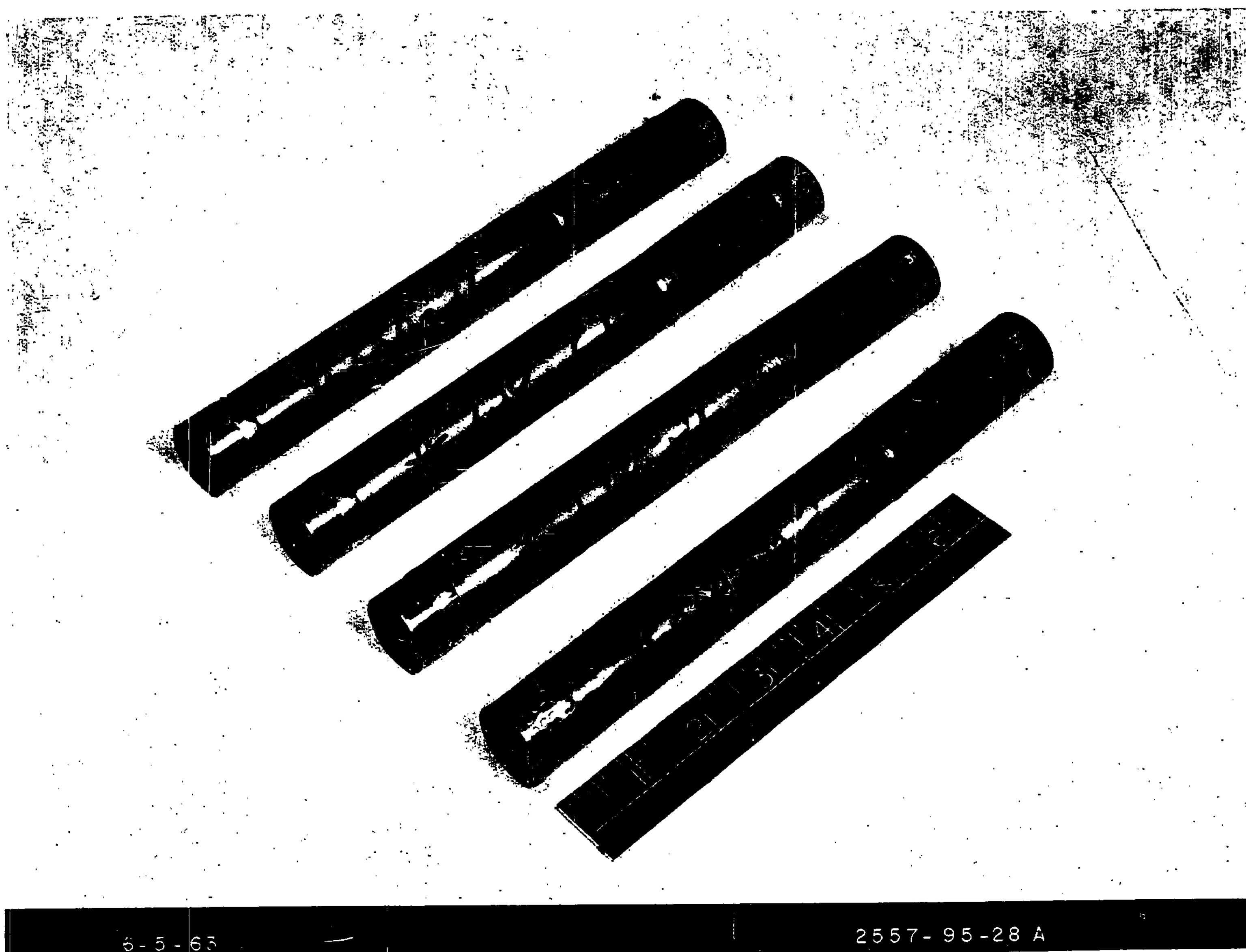


Figure 30. Simple Butt Fusion Weld Joints in One Inch Diameter AM 350 Stainless Steel Tube Specimens

FIGURE 31. FRACTURE OF ONE INCH DIAMETER AM 350 STAINLESS STEEL WELDED JOINT SPECIMEN TESTED IN STRESS REVERSAL BENDING AT 600 F. FAILURE BEGAN IN HEAT AFFECTED ZONE ADJACENT TO WELD.

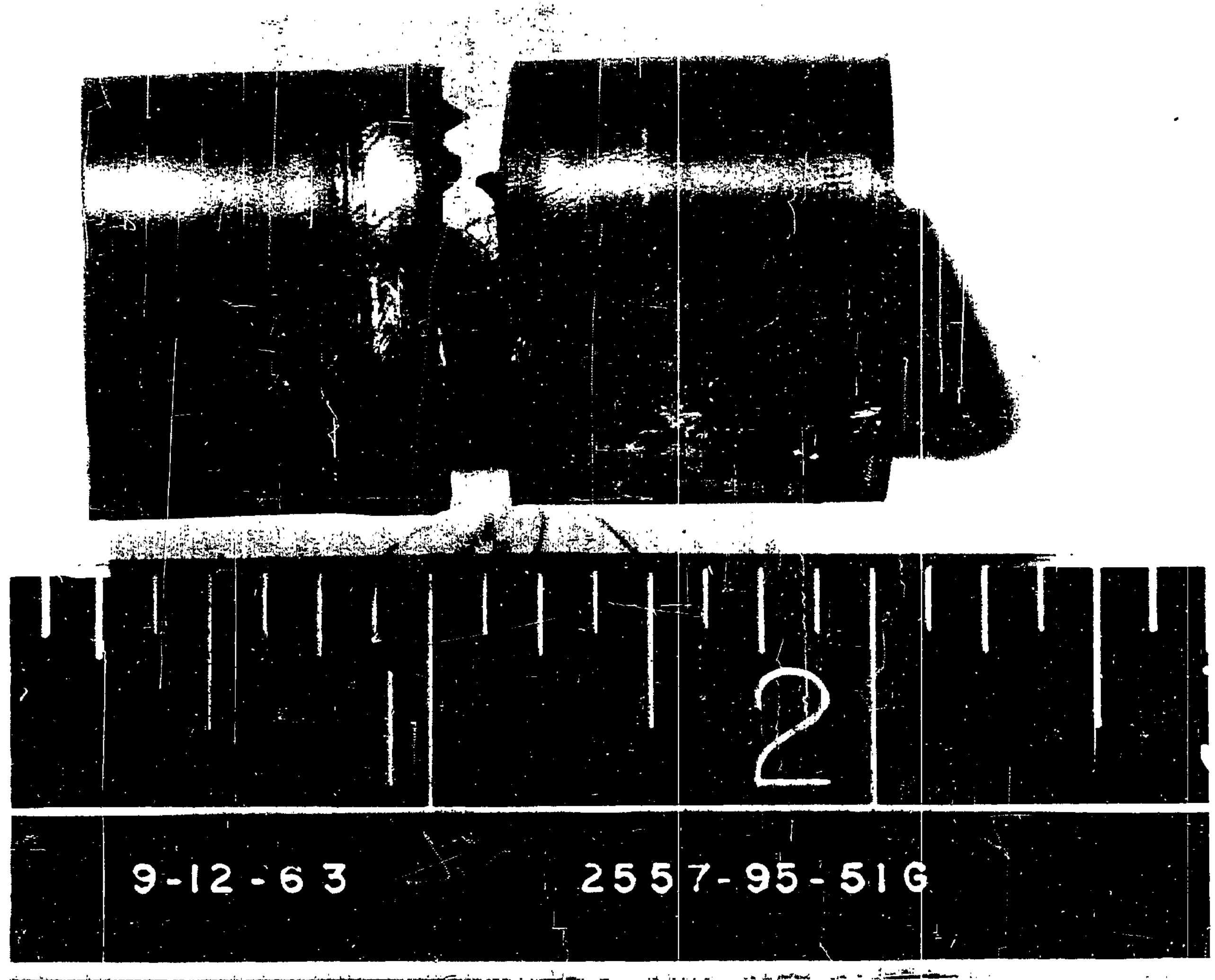


FIGURE [illegible]. FRACTURE SURFACES OF ONE INCH DIAMETER AM 350 STAINLESS STEEL WELDED JOINT SPECIMEN TESTED IN STRESS REVERSAL BENDING AT 600 F. SURFACES SHOW MARKINGS INDICATIVE OF FATIGUE FAILURE.

4.4 WELDING RENE'41 ALLOY TUBING

Phase I Welding of 3/4 Inch Diameter Rene'41 Tubing

The Rene'41 tubing which was welded during the Phase I part of the program was 3/4 inch diameter by .030 inch wall. The initial attempts to weld the Rene' 41 tubing were made with the one-inch maximum diameter welding tool, but they were unsuccessful because of the insufficient shielding gas coverage of the weld area. The shielding gas inlet in this tool does not rotate with the tungsten electrode. The welding unit which had been designed and built under this program for welding three-inch maximum diameter tubing included a rotating gas inlet. This rotating shielding-gas inlet moved with the electrode and so produced an improved inert gas shielding coverage of the weld area. However, when the 3/4 inch diameter tubing was welded with this tool, the rotating gas inlet was located about one inch from the weld surface. A ceramic cup was bonded around the gas inlet and the electrode, as shown in Figures 11 and 12, pages 44 and 45, to provide still further improvement in the direction of the shielding gas toward the weld surface. This change resulted in the gas inlet and electrode rotating around the tube as a unit, and the cup was able to direct the flow of the shielding gas directly on the weld surface. The modification solved the shielding gas coverage problem and permitted the joining of 3/4 inch diameter Rene'41 tubing with satisfactory welds.

Good quality weld joints in 3/4 inch diameter Rene'41 tubing were made in both the vertical and horizontal positions. It was necessary, due to the preheating effect, to reduce the welding current after about two-thirds of the weld length around the tube had been completed. This condition was more apparent with the tubing in the horizontal than in the vertical position, and is the result of excessive heat which increases puddle fluidity resulting in excessive drop-through or sagging of the weld bead.

A number of welds were inspected metallographically and radiographically and were found to be satisfactory. One joint was found to have lack of penetration when inspected with a borescope. This joint was subsequently repaired by rewelding using a weld schedule with a current increase of 2 amperes. Re-inspection of the joint after this repair showed a good weld with excellent penetration.

An oxidized surface was observed on the Rene' 41 welds. This oxide indicated that the cleaning by wire brushing and acetone wiping was not removing all of the oxide from the tube. To insure removal of the scale and other contaminants which might have remained after normal cleaning, the surfaces to be welded were also cleaned with sandpaper. This procedure resulted in welds with cleaner surfaces.

Welding 1/8 Inch Rene'41 Alloy Tubing

The weld schedule for joining the 1/8 inch diameter by .010 inch wall Rene'41 alloy tubing qualification test specimens is presented in Table X, page   The general procedure included the use of fitted sleeves machined

from 3/16 inch diameter Rene'41 rod. This welding procedure was the same as described previously for weld joining the 1/8 inch diameter Type 321 stainless steel tubing.

Two preliminary burst test weld joint specimens were made with the 1/8 inch diameter by .010 inch wall Rene'41 alloy tubing. The first specimen successfully passed the proof pressure and leakage tests at both -320 F and 1500 F, and was being prepared for the 1500 F burst test when it was accidentally damaged to an extent that precluded completion of the testing with this specimen. The second 1/8 inch diameter Rene'41 alloy tube welded joint specimen also successfully completed the -320 F, room temperature, and 1500 F proof pressure and leakage tests. However, during pressurization of this specimen at 1500 F for the burst test this second specimen developed cracks in the parent metal tubing. The failure was attributed to defects in the tubing material. The defects may have resulted from stress corrosion of the longitudinal weld seam of the parent metal tubing. Examination by the tubing supplier indicated that this defect should be limited to the one length of tubing from which the specimen had been made. Therefore, the remaining qualification test specimens were prepared from a different length of 1/8 inch diameter Rene'41 alloy tubing. The qualification test specimens were welded, inspected visually and radiographically, and found to have welds of good quality. The end plugs were installed in these specimens by induction brazing rather than by manual TIG welding. This was done as a matter of convenience. A typical test weld joint of a specimen from this group is shown in Figure 33.

Difficulty in handling these small-diameter thin-wall test specimens resulted in a number of premature test failures due to deformation of either the parent tubing or of the end fittings. The first of the new 1/8 inch diameter Rene'41 alloy tube welded burst test specimens was also unable to be completely tested due to distortion of the parent tubing. This appeared again to be the result of inadvertant damage during handling or installation in the test fixture. The second specimen successfully passed the proof pressure, leakage, and burst test requirements. This specimen is shown in Figure 33. One specimen was tested in stress reversal bending at -320 F and failed in the parent metal tubing after 16,150 cycles at 88,500 psi bending stress at the joint centerline. The welded test joint was undamaged, Figure 34. One stress reversal bend specimen was tested at room temperature. Failure of the test jig during this test damaged the specimen by distortion of the parent tubing, but again the test weld was intact. One stress reversal bend specimen was tested at 1500 F and failed after 125,700 cycles at a stress of 54,500 psi, the fracture occurring in the weld heat affected zone directly adjacent to the fusion zone. The failure at 1500 F appears to be similar to those previously described for the AM 350 stainless steel specimens tested at 600 F, and appears to be due to fatigue.

Welding One Inch Diameter Rene'41 Alloy Tubing

A limited number of weld joints were made in the one inch diameter by 0.065 inch wall Rene'41 alloy tubing, but not enough to develop a satis-

FIGURE 33. 1/8 INCH DIAMETER RENE' 41 ALLOY TUBE TEST WELD JOINT AFTER SUCCESSFUL COMPLETION OF BURST TEST AT 1500 F.

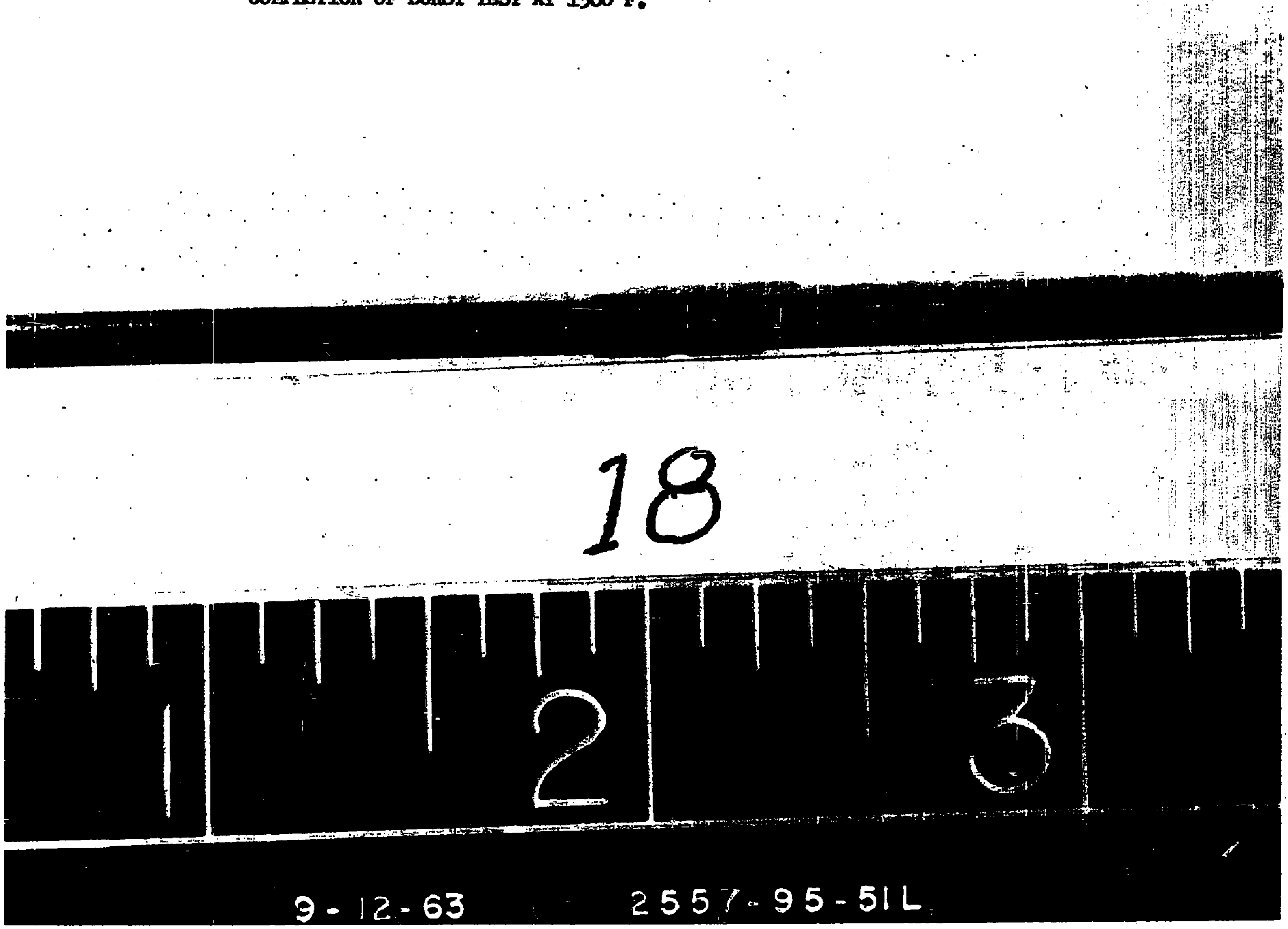
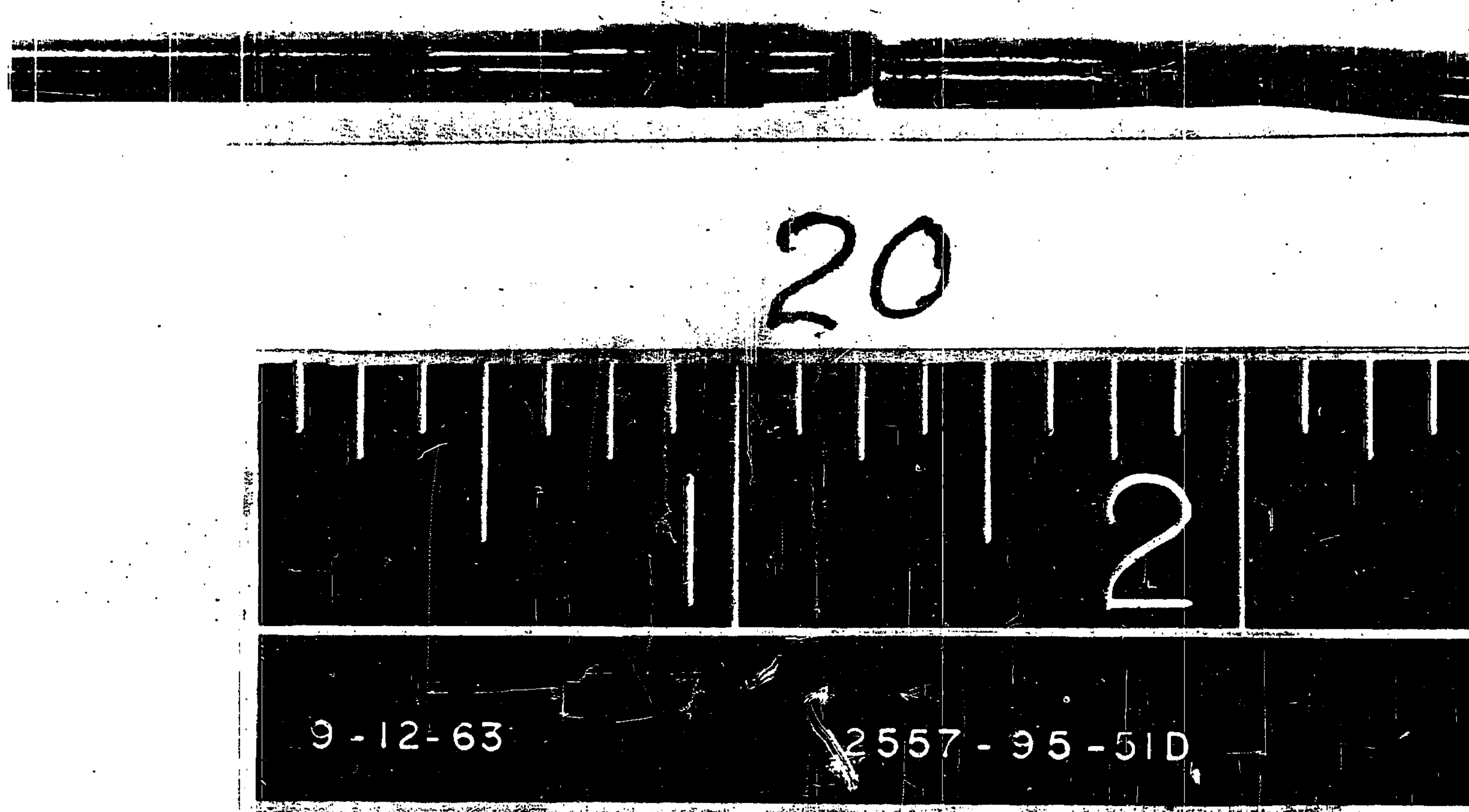


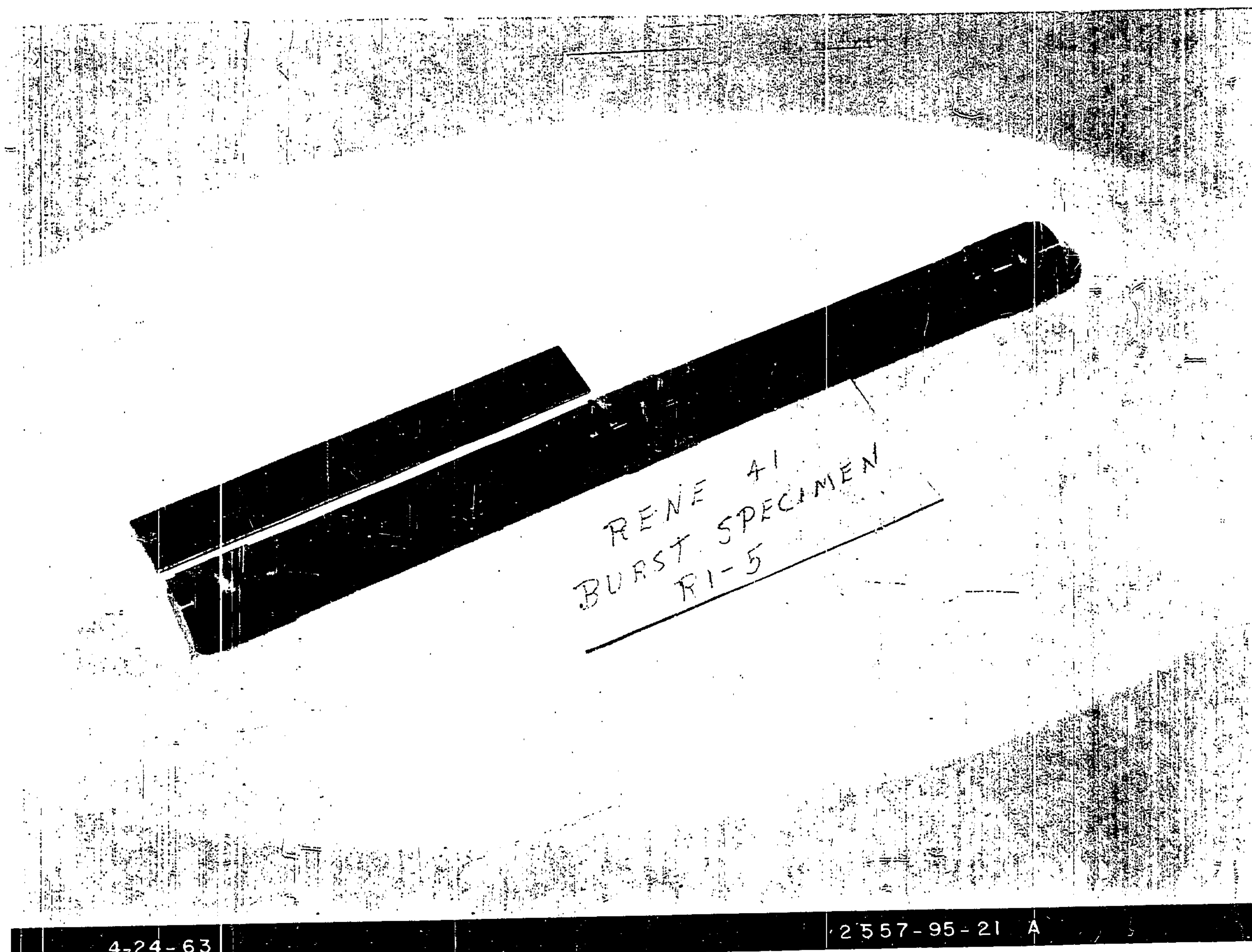
FIGURE 34. 1/8 INCH RENE' 41 ALLOY TUBE WELDED JOINT SPECIMEN FRACTURED DURING -320 F STRESS REVERSAL BEND TEST SHOWING DISTORTION OF TUBE AND FAILURE AWAY FROM AREA OF TEST JOINT.



factory weld schedule. One such weld, a sleeve-type joint, is shown in Figure 35. During the course of this welding close examination revealed a number of material and fabrication defects in the one inch diameter Rene'41 alloy tubing which had been procured for this program. The inside surface of the tubing was found to have such defects as long score and gouge marks and also a series of raised circumferential rings. These defects are believed to have been produced during the tubing manufacturing operations. In addition, this tubing, which was of the welded and redrawn type, had excessive undercut along one, and in some lengths along both, internal edges of the longitudinal tubing weld seam. One parent metal and one welded specimen were prepared for preliminary burst testing in order to evaluate the effect that these defects might have on the performance and suitability of the tubing material for use in this program. The parent metal specimen tested at 1500 F developed a leak after only 15 seconds at the burst pressure of 8000 psig. Metallographic examination of this specimen showed that the leak was in a crack in the longitudinal tubing weld. Further examination revealed that defects in the form of inclusions and also porosity were present in a number of sections along the length of this weld. The welded joint preliminary burst specimen, shown in Figure 35, also failed during the proof pressure and leak test at 1500 F after successfully passing the proof pressure and leak test at -320 F. This specimen, as noted above, had been determined to be unsatisfactory for test after X-ray inspection revealed what appeared to be oxide folds in the test weld. However, the specimen was tested in order to determine the extent in which this defect would affect the specimen performance. Failure of the specimen in the weld heat-affected zone appeared to have taken place in two stages, after originating in the oxide-fold areas in the longitudinal seam weld of the tubing. The first part of the failure is believed to have started and propagated a certain amount during the -320 F testing, with final failure occurring during the testing at 1500 F. Views of the fracture are shown in Figure 36.

A careful study was made of the possibility of rework by which the tubing might be made usable for this program. The problem of tubing quality and possible rework was fully discussed with representatives of the tubing supplier. It was finally determined that most of the scores and gouges might be removed from the tubing ID by honing the ID to a larger size. The resultant tubing would have a wall thickness below that required to meet the specified internal pressure and stress conditions of the qualification tests. Furthermore, the inclusions and porosity defects in the longitudinal tubing weld would still present a problem.

After a full review, it was decided that it would not be possible to accomplish rework of this tubing in a manner which would satisfy the program requirements, and also that specimens could not be manufactured from such reworked tubing which would be acceptable to meet the program qualification test requirements. Therefore, with the concurrence of the USAF Project Engineer, the decision was made to reject this tubing and return it to the supplier, and also to suspend all further work under this program on the one inch diameter Rene'41 alloy tubing.


RENE 41
BURST SPECIMEN
R1-5
4-24-63
2557-95-21 A

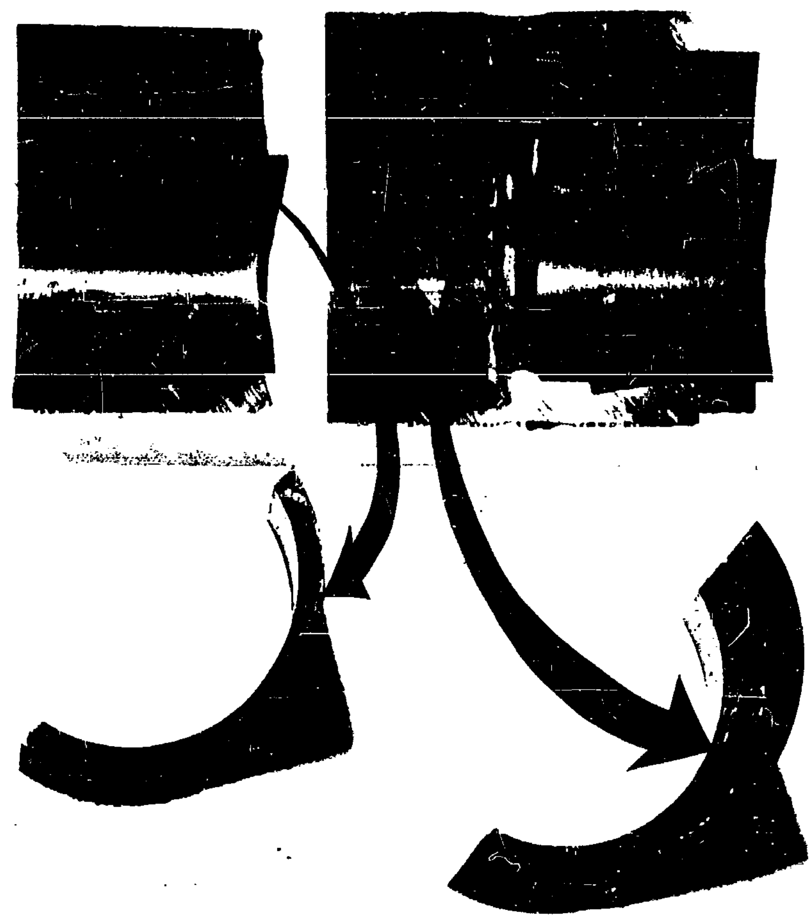


FIGURE 36.

FAILURE IN HEAT AFFECTED ZONE OF TEST WELD JOINT IN ONE INCH DIAMETER RENE' 41 ALLOY TUBING PRELIMINARY BURST TEST SPECIMEN. FRACTURED SURFACES SHOW MARKINGS INDICATING FATIGUE FAILURE WHICH PROPAGATED IN TWO SEPARATE STAGES.

4.5 WELDING 6061 ALUMINUM ALLOY TUBING

Initial Investigation of Aluminum Welding Methods

The welding units which had been developed during the first part of this program for joining the stainless steel and Rene'41 alloy tubing were also used in early efforts to join 6061-T6 aluminum alloy tubing. Many approaches were tried, but no satisfactory method could be developed for "in place" fusion welding of the aluminum tubing using these tools and the techniques which had been utilized with the other materials. The high thermal conductivity, extreme fluidity of the weld puddle, and the oxide layer which formed on the surface of the weld, make it virtually impossible to join aluminum tubing using these techniques. In addition, small variations in fit-up, either between the sleeve fitting and the tube or between the tube ends, caused serious heat shorts during welding.

A gap between the butting ends of the tubes resulted in lack of fusion on one side of the joint. A gap between the sleeve fitting and the tube also resulted in lack of fusion in the tube face of the joint. In some cases sufficient heat was transferred across the gap between the sleeve fitting and the tube to cause the tube to melt, but even then the sleeve and tube weld puddles remained separate and did not wet due to the oxide on the upper surface of the tube puddle. In an attempt to cause the puddles to wet, the surface of the tube was coated with Solar 202 weld flux. This first attempt to use flux produced better wetting, but also caused excessive porosity in the weld because of entrapment of gases between the sleeve and the tubing.

A large gap between the tube and the sleeve fitting also caused excessive melting in the sleeve and resulted in fouling of the tungsten electrode. Another detrimental effect of poor fit-up between the sleeve fitting and the tube was that it caused a great variation in the preheating effect on the tube. This variation made it extremely difficult to predict where the weld puddle would initially drop through the tube, and also to control the penetration once the puddle did drop through. Without control of the puddle drop-through and penetration, automatic or "blind" welding of aluminum tubing joints cannot be accomplished.

In order to determine whether sufficient heat control was available for "in place" weld joining of aluminum tubing, several joints were welded in which the tube ends were butted together but the sleeve was eliminated. Puddle control was much better using this technique, but it was still not possible to make any joints without producing excessive concavity and drop-through.

Other methods of adding filler material were then considered in addition to use of a sleeve. Joints were prepared in which rings having a "tee"-shaped cross-section were employed in place of the full cylindrical sleeve. The use of these "tee"-shaped cross-section rings caused additional problems in fit-up of the tube ends and also required tack welding for location purposes. During the subsequent welding of the tube joint, heat shorts occurred at each of the tack welds with a resulting lack of

fusion. Nevertheless, the use of the "tee"-shaped cross-section rings did show some promise. But, within the resources available to this program, the automatic addition of filler wire appeared to be the only method of filler material addition which had the promise of resulting in a semi-automatic production-type process for welding aluminum tubing. In addition, it should be noted that while the major problem which had been encountered was that of obtaining a controllable heat input to the joint, other important problems were also evident. The weld cross section exhibited much porosity and occasional cracks, emphasizing the requirement for filler wire addition and also for stringent cleaning procedures. Standard practices for the welding of 6061 aluminum alloy include the addition of either 4043 or 5356 aluminum alloy filler wire.

Further Development of Aluminum Tube Welding Techniques

The development of a method for the addition of filler material during welding was accomplished by the incorporation of a small wire feeder as a part of the welding tool. A "bread board" type tool was designed and built by NAA during the Phase II part of this program. This tool, which is shown in Figure 37, permitted the addition of short lengths of filler wire during the welding of joints in one inch diameter tubing. Use of this tool was shown to provide sufficient reproducibility of weld parameters to warrant the fabrication of the aluminum tube specimens for qualification testing.

The following procedure was developed for welding the one inch diameter by 0.058 inch wall 6061-T6 aluminum alloy tubing qualification test specimens. The tube ends to be welded were cleaned by wiping with acetone. The cleaned ends were then coated with Solar 202 flux. The Solar 202 flux was used in order to eliminate unacceptable weld porosity. Chemical cleaning and/or wire brushing of the tube ends had been investigated, but these alone did not eliminate porosity. But, when the flux was used, only an acetone wipe was required prior to welding in order to obtain joints within acceptable porosity limits. 4043 aluminum alloy filler wire was used for all welding of the 6061-T6 aluminum alloy tube joints. After welding, the inside surfaces of the tubing were cleaned by flushing with warm water, which removed any flux residue from the joint area. Use of this flux in TIG welding of butt joints in 6061 aluminum alloy and in other aluminum alloys has been extensively investigated by the Rocketdyne division of North American Aviation, Inc., and also by NAA/LAD. It is reported that use of Solar 202 flux does not significantly affect the quality, mechanical properties, or corrosion resistance of aluminum alloys, References (66) and (67).

The "bread board" type welding tool did not have provision for holding the tube ends in place at the start of the welding operation. Therefore, after the tool itself had been clamped on the end of one of the tubes, it was necessary to place the end of the other tube in position and also to continue to hold the tube in place by hand during the welding operation. After approximately two-thirds of the circumference of the joint had been welded, the weld current was reduced or down sloped manually in order to compensate for the effect of preheating in the

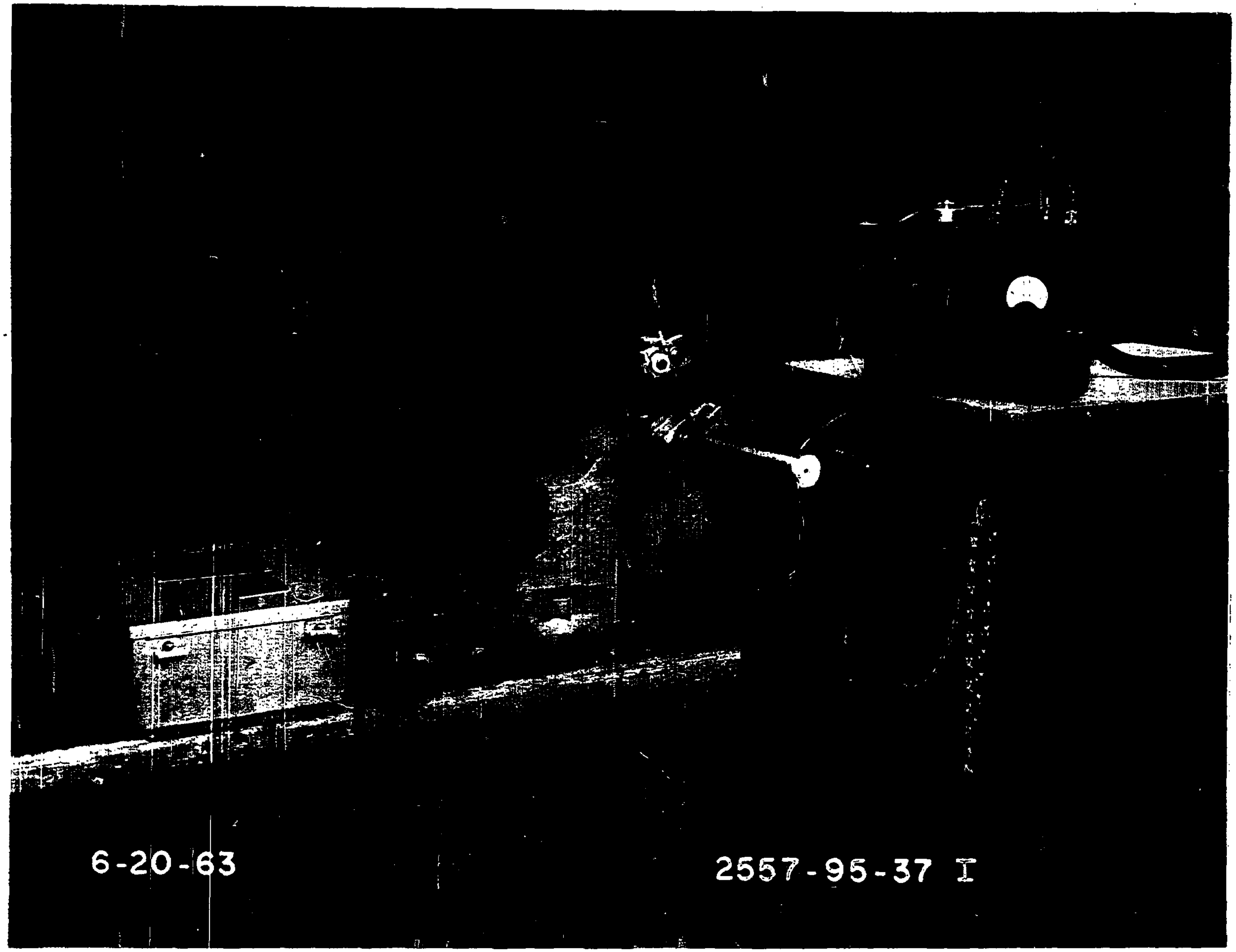


Figure 37. 'Breadboard' Tube Welder with Filler Wire Feeder and Controls

region still to be welded. A close-up view of the welding operation is shown in Figures 38 and 39.

The one inch diameter 6061-T6 aluminum alloy tube qualification test specimens were welded, inspected visually and radiographically, and submitted for testing. The end plugs installed in typical aluminum qualification specimens are shown in Figure 40, which also shows the typical appearance of the weld joints. Of the twelve aluminum alloy one inch diameter welded specimens which were fabricated for qualification testing, two specimens required rework due to unacceptable porosity shown by radiographic inspection. The weld joints in these specimens were cut apart, prepared again, and completely rewelded. The porosity in the initial welds probably resulted from inadvertant variation in the welding parameters.

The qualification test specimens successfully passed the proof pressure, leakage, burst, stress reversal bend at -320 F, thermal shock and pressure impulse tests. One of the first preliminary specimens was burst tested at 200 F for information purposes even though it contained unacceptable porosity. This specimen failed due to a leak detected at 1000 psi. The specimen which was tested in stress reversal bending at 200 F failed after 27,000 cycles at 11,900 psi bending stress at the joint centerline. Inspection of the fracture after testing indicated a typical fatigue failure in the weld heat-affected zone directly adjacent to the fusion zone, Figure 41.

Two specimens were tested in vibration at 200 F. One failed in the end fitting leaving the welded union intact, and the second failed in fatigue in the weld heat-affected zone directly adjacent to the fusion zone, Figure 42. In this area the weld bead had decreased in width and increased in height, presumably increasing the effective notch stress concentration factor. The specimen life of 137,000 cycles at the specified test stress level of 75 percent of the static yield strength is about all that can be expected at this high load level. A life of 2 x 10^6 appears to be beyond the capabilities of the material at this stress level, Reference (68).

Welding 1/4 Inch Diameter 6061-T6 Aluminum Alloy Tubing

In an effort to develop a satisfactory combination of weld parameters a number of test welds were made in the 1/4 inch diameter 6061-T6 aluminum alloy tubing using the procedures noted above. A number of variations in weld current, travel speed, and wire-feed speed were made, but it was never possible to obtain the depth of penetration required without simultaneously carrying such a large weld puddle that eventually the tube collapsed.

Some manual welding was attempted, in addition to the semi-automatic welding, in order to determine whether the problem was due to the semi-automatic weld tooling. The same results were obtained. Based on these tests, it does not appear feasible at this time to join the 1/4 inch diameter by 0.042 inch wall 6061-T6 aluminum alloy tubing using the semi-

Figure 38. General View of Aluminum Tube Welding with "Bread Board" Tool Showing Hand Control of Current.

Figure 39. Close-Up View of Aluminum Tube Welding Showing Filler Wire Addition to Arc.

Figure 40. Welded 6061 Aluminum Alloy Tube Specimens Showing Test Joints and End Plugs

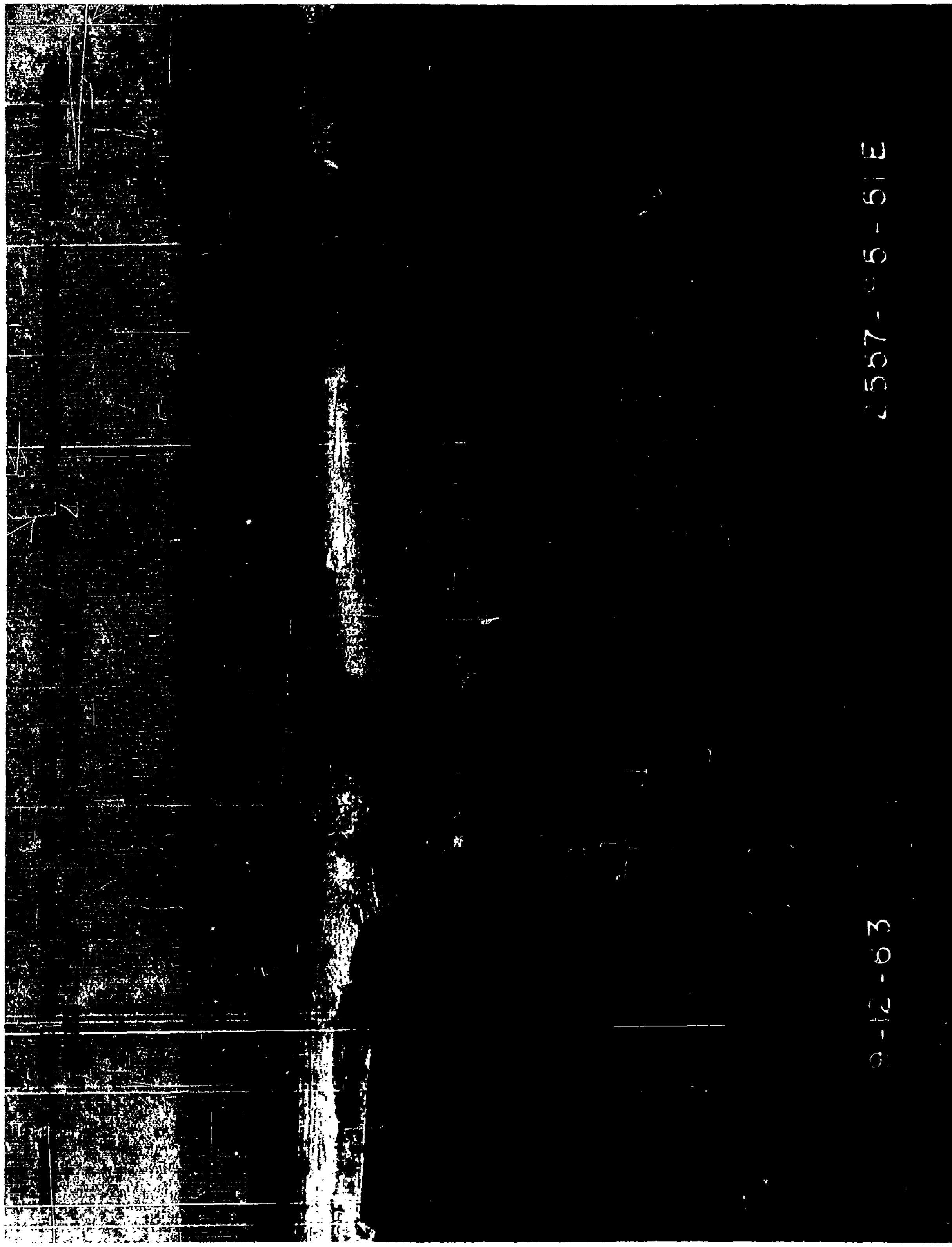

9-12-63

FIGURE [illegible]. FRACTURE SURFACES OF ONE INCH DIAMETER 6061-T6 ALUMINUM ALLOY TUBE WELDED JOINT SPECIMEN SHOWING FATIGUE MARKINGS. SPECIMEN FAILED IN TEST WELD HEAT-AFFECTED ZONE DURING VIBRATION TEST AT 200 F.

automatic TIG welding equipment and procedures developed in this program, even with the added automatic wire feed equipment.

4.6 GENERAL COMMENTS ON WELD JOINT QUALIFICATION TEST RESULTS

The welded joint specimens generally proved to be satisfactory in qualification testing except for those tested in stress reversal bending at elevated temperature. Careful examination of the failed specimens indicated that all the elevated temperature stress reversal bend specimens failed in the weld heat-affected zone. The requirement for high strength weld joints of a life of 200,000 cycles at a bending stress of 75 percent of the tensile yield is beyond the S-N curve for even the parent AM 350 and Rene' 41 tubing, although such a life can be achieved with the low yield strength materials such as 347 stainless steel. The notch stress concentration factor due to the change in section from the weld zone into the tube wall heat-affected zone, and the lower strength of this zone, are the reason for the failure in this area. If it is desired to have long fatigue life demonstrated, testing to verify this capability should be conducted at lower stress levels, such as forty to sixty percent of the parent metal tensile yield strength. This would be around the "knee" portion of a typical "S-N" curve, and would provide longer fatigue life, Reference (69).

A number of tables summarizing the complete test results have been included in Appendix I, page 168.

5. TUBE BRAZING

5.0 GENERAL

The concept of using brazed joints for connecting fluid system lines is not new, but it is only in the last few years that such joints have been used extensively in the hydraulic, pneumatic and propellant systems of aircraft and rocket propelled vehicles. Not until recently have the brazing technology and equipment required for making brazed joints "in place" and under field conditions become sufficiently well developed to make the use of all-braze joined systems practical.

The techniques for making fluid system brazed joints by induction heating at a considerable distance away from the power supply were first developed by the Los Angeles Division of North American Aviation, Inc., for use in the construction of the X-15 rocket propelled research vehicle, References (60) to (64). These techniques and equipment for "remote" induction brazing were further developed and improved for use in the assembly of fluid system tubing for the XB-70 aircraft, References (43),(46), (51), (70) and (71). The work reported in this Section has utilized this previous technology to establish new improved brazing techniques and sleeve fitting designs for use in the assembly of propellant and pneumatic fluid systems of rocket propulsion vehicles.

5.1 INVESTIGATION OF BRAZING ALLOYS

Summary of Brazing Alloy Selection

The initial selection of brazing alloys for the preliminary evaluation studies was made on the basis of the results of a review of the technical literature and also of previous brazing investigations which have been conducted by North American Aviation, Inc. The candidate brazing alloys which were selected initially are shown below, and are listed according to the tubing system materials which they were intended to join.

TUBING MATERIALS	CANDIDATE BRAZING ALLOYS
AISI Type 347 Stainless Steel	72Ag-28Cu-Li 72Au-22Ni-6Cr 82Au-18Ni
AM 350 Stainless Steel	72Ag-28Cu-Li
Rene' 41 Alloy	60% Palladium + 40% Nickel + Lithium 72Au-22Ni-6Cr 35Au-3Ni-62Cu 82Au-18Ni Ni-Cr-B Ni-Cr-B-Si-Fe

The brazing alloy investigation considered a number of different criteria on the basis of which the final alloy selection would be made. The criteria which were felt to be most important were:

(1) Wettability and flow
(2) Compatibility with the tube and fitting sleeve materials
(3) Compatibility with the system fluid
(4) Corrosion resistance
(5) Strength at elevated temperatures

The results of the preliminary brazing alloy evaluation studies led to the elimination of most of the alloys which had been selected initially. The reasons for elimination of these brazing alloys were either poor wetting of the surface of the tubing system material or insufficient shear strength at the required tubing system maximum operating temperature.

Several additional brazing alloys were then evaluated for improved wetting and flow characteristics and for elevated temperature shear strength. These were the 82Au-18Ni-Li and 70Au-22Ni-8Pd alloys. Selection of the brazing alloys to be used for manufacture of the qualification test specimens was made on the basis of the information obtained from the review of the technical literature and the data from the wettability, flow, and block shear tests. After satisfactory wetting characteristics had been determined, final selection of the brazing alloy was made primarily on the basis of elevated temperature block shear strength. At the maximum operating temperature of the particular system the selected brazing alloy had to have a sufficiently high shear strength that the fitting sleeve could be designed with a reasonable overall length, close to the dimension of 1.5 times the tube diameter requested by the Air Force.

The chemical composition of each of the candidate brazing alloys tested during this investigation are given in Table XII. The brazing alloys which were finally selected for the Qualification Test program are listed below along with the tube and fitting sleeve materials with which they were used.

TUBING MATERIALS	FITTING SLEEVE MATERIALS	SELECTED BRAZING ALLOY
Type 347 Stainless Steel	Type 347 Stainless Steel	72Ag-28Cu-Li
AM 350 Stainless Steel	AM 355 Stainless Steel	82Au-18Ni-Li 70Au-22Ni-8Pd
Rene' 41 Alloy	Rene' 41 Alloy	82Au-18Ni-Li 70Au-22Ni-8Pd

TABLE XII. COMPOSITIONS OF CANDIDATE BRAZING ALLOYS

BRAZING ALLOY	CHEMICAL COMPOSITION (Percent)										MELTING TEMPERATURE RANGE	MINIMUM RECOMMENDED BRAZING TEMPERATURE
	Au	Ag	Ni	Pd	Cr	Cu	Si	Li	B	Fe		
72Ag-28Cu-Li	--	71.8	--	--	--	28	--	0.2	-	--	1410 F	1450 F
72Au-22Ni-6Cr	72	--	22	--	6	--	--	--	-	--	1785-1835 F	1950 F
35Au-3Ni-62Cu	35	--	3	--	--	62	--	--	-	--	1787-1886 F	1890 F
82Au-18Ni	82	--	18	--	--	--	--	--	-	--	1742 F	1850 F
Ni-Cr-B	--	--	81.5	--	15	--	--	--	3.5	--	1930 F	2150 F
Ni-Cr-B-Si-Fe	--	--	83.5	--	6	--	5	--	3	2.5	1830 F	1900 F
60Pd-40Ni-0.3Li	--	--	40	59.7	--	--	--	0.3	-	--	2100 F	2150 F
82Au-18Ni-Li	81.7	--	18	--	--	--	--	0.3	-	--	1710 F	1825 F
70Au-22Ni-8Pd	70	--	22	8	--	--	--	--	-	--	1825-1910 F	1950 F

The factors of corrosion resistance and compatibility of the braze alloys with the system fluids have been discussed in Section 2, MATERIAL SELECTION, of this report. The other braze alloy selection criteria are discussed in the following paragraphs.

Wettability and Flow

The wetting and flow characteristics of the candidate brazing alloys were determined by heating small specimens of each of the tube and fitting sleeve materials on which had been placed a piece of brazing alloy. The specimens were heated to progressively higher temperatures in a controlled atmosphere tube furnace, with a dried argon gas atmosphere in both the hot and cold zones of the furnace. Temperature was monitored by means of thermocouples attached to the back side of the test specimens. After the desired temperature was reached the specimen was stabilized at that temperature for a few minutes. The specimen was then withdrawn from the hot zone of the tube furnace and was allowed to cool in the inert argon atmosphere.

The wetting and flow characteristics of the melted braze alloys were then evaluated visually. Three typical test specimens which exhibit different degrees of wetting and flow are shown in Figure 43. The wettability and flow characteristics of the candidate brazing alloys with the tubing system materials are presented in Table XIII. It should be noted that the results of this type of test, although qualitative in nature, do establish the wetting compatibility of the selected materials and also the approximate brazing temperature for the braze alloy-tube material combination.

Brazing of AISI Type 321 and Type 347 Stainless Steels

AISI type 321 stainless steel tubing was used to develop the initial brazing parameters for the system in which type 347 stainless steel tubing will be used for the Qualification Test program. The two steels are very similar in their brazing properties.

All of the candidate braze alloys selected for use with type 347 stainless steel tubing have exhibited satisfactory wetting and flow characteristics. The 72Ag-28Cu-Li alloy appeared to wet and flow slightly better than did the 72Au-22Ni-6Cr and 82Au-18Ni alloys without lithium. This is to be expected since the lithium addition greatly improves wetting and fluidity of brazing alloys. The block shear strength of the 72Ag-28Cu-Li braze alloy was determined to be satisfactory for the requirements of the AISI type 347 stainless steel tubing system. Both the 72Ag-28Cu-Li silver-base alloy and the 82Au-18Ni gold-base alloy were selected for further evaluation for brazing joints in type 347 stainless steel tubing.

The 72Ag-28Cu-Li brazing alloy was used as a wire preform and was preplaced inside a grooved sleeve fitting, as shown in Figure 44. The 82Au-18Ni brazing alloy was also used as a preformed wire ring preplaced inside a grooved sleeve fitting. The joint clearance between the tubing and the sleeve fitting was 0.003 inch for the 82Au-18Ni alloy initial evaluation specimens. Because of the greater fluidity of the 72Ag-28Cu-Li braze alloy, a slightly closer joint clearance of 0.0025 inch was used.

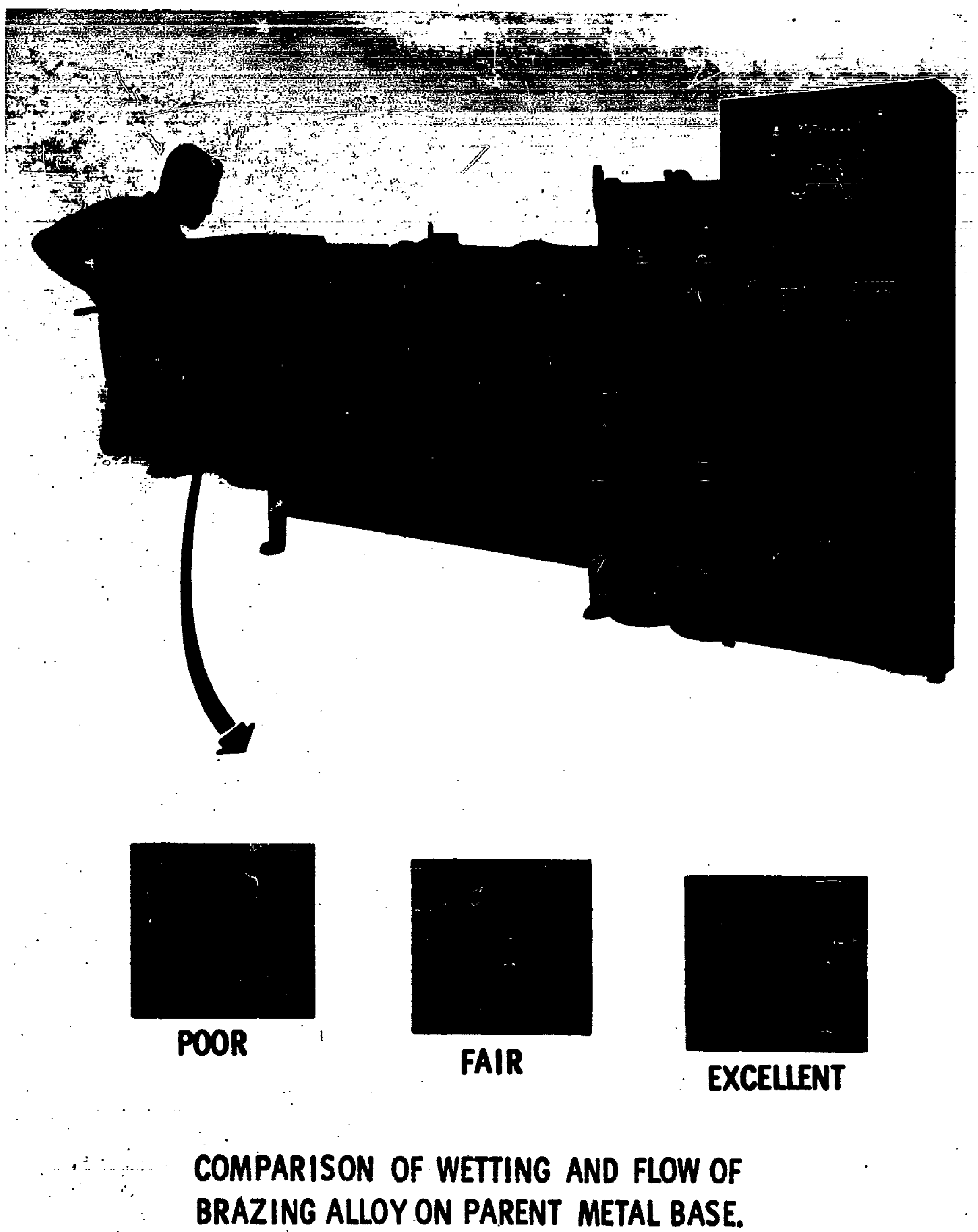
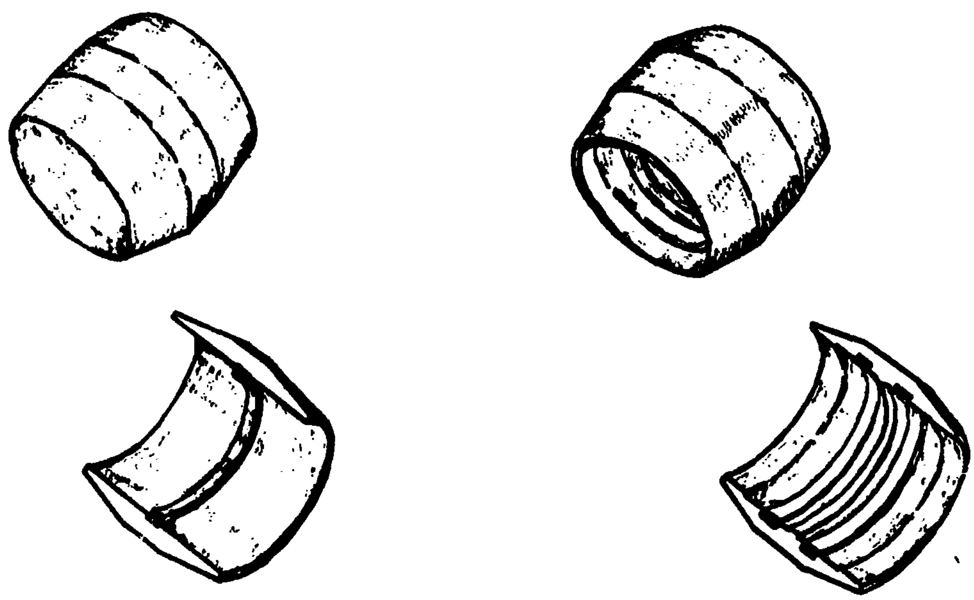


Figure 43. Wettability Test of Brazing Alloys

TABLE XIII. WETTABILITY AND FLOW OF BRAZE ALLOYS

BASE (TUBE) MATERIAL	CANDIDATE BRAZING ALLOY	WETTABILITY	FLOW
AISI Type 321 or 347 Stainless Steel	72Ag-28Cu-Li	Good	Good
	72Au-22Ni-6Cr	Good	Fair
	82Au-18Ni	Good	Fair
AM 350 Stainless Steel	72Ag-28Cu-Li	Good	Good
	82Au-18Ni-Li	Excellent	Excellent
Rene' 41	72Au-22Ni-6Cr	Good	Fair
	35Au-3Ni-62Cu	Good	Fair
	82Au-18Ni	Good	Fair
	60Pd-40Ni-0.3Li	Good	Good
	Ni-Cr-B	Fair	Poor
	Ni-Cr-B-Si-Fe	Fair	Poor
	82Au-18Ni-Li	Excellent	Excellent
	70Au-22Ni-8Pd	Excellent	Excellent

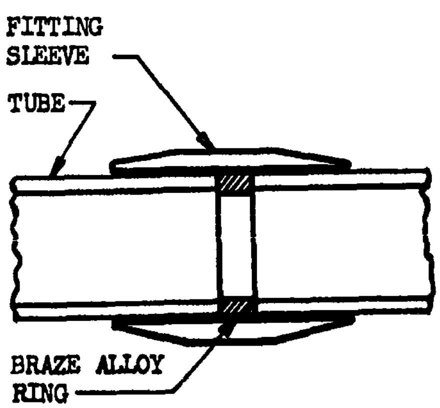


STRAIGHT-THROUGH BORE
FITTING SLEEVE

Single ring of braze alloy is preplaced inside fitting sleeve between tube ends.

GROOVED-BORE
FITTING SLEEVE

Two preform braze alloy rings are preplaced in reservoir grooves machined in bore of fitting sleeve.



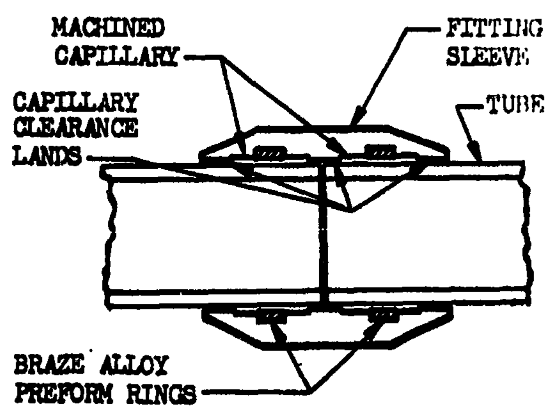


FIGURE 44. CONFIGURATIONS OF FITTING SLEEVES FOR BRAZE JOINING TUBING.

The most satisfactory brazed joints made with type 321 stainless steel tubing were those brazed with the 72Ag-28Cu-Li alloy. During the preliminary evaluation work joints were produced with this braze alloy which were 95 percent void free. However, the first joints brazed with 72Ag-28Cu-Li alloy and type 321 stainless steel tubing had many voids. These voids were determined to have been caused by mill markings on the tubing which the chemical cleaning operation had not completely removed. The mill markings can be removed by any suitable method, such as sanding with fine emery paper. For these test joints, vapor honing was used to remove the mill markings from the tubing surface prior to the regular cleaning operation.

The Au-Ni-Cr and Au-Ni alloys produced brazed joints with type 321 stainless steel tubing which were approximately 80 percent void free. The quality of the joints brazed with these gold-base alloys not containing lithium might have been further improved if a nickel plating technique had been used in the same manner as that described later for the Rene' 41 tubing brazed joints. However, the nickel plating procedure is not considered acceptable by the Air Force for production use.

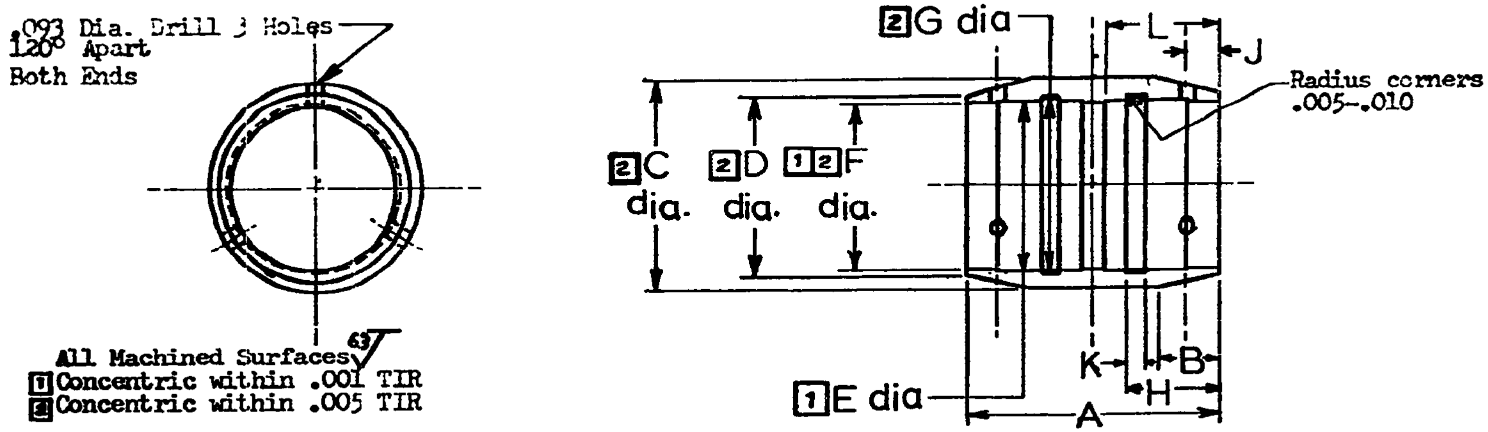
The one-inch and the three-inch diameter type 347 stainless steel tube specimens for qualification testing were made with 72Ag-28Cu-Li brazing alloy. The brazing alloy was in the form of a preformed flat wire ring, and was preinserted into the machined reservoir groove of the fitting sleeve. The fitting sleeves were machined to form a slip fit with the as-received tubing diameter. The capillaries for braze alloy flow were machined into the inside diameter of the fitting sleeves. The capillary depth was maintained between a minimum of 0.001 inch and a maximum of 0.004 inch. The dimensions of the fitting sleeves for the qualification test specimens are given in Table XIV.

Brazing of Three-Inch Diameter Type 347 Stainless Steel Tubing

Following satisfactory completion of the manufacture of the brazed one inch diameter AISI type 347 stainless steel qualification test specimens, studies were begun on braze joining the three-inch diameter by 0.250-inch wall type 347 stainless steel tubing. The purpose of these studies was to determine the feasibility of brazing large diameter heavy-walled tubing.

Brazing studies and braze tube-joint usage for the XB-70 air vehicle have been limited to a maximum tubing diameter of 1-7/8 inches for the high pressure, or heavy-wall tubing, fluid systems. Brazed joints have been made in large diameter tubing, up to six inches in diameter, but such joints have been used only for low pressure systems where the tubing wall thickness rarely exceeded 0.062 inch.

The three-inch diameter tube joint components were cleaned by the procedure described on page 115 later in this Section, which involves hot alkaline cleaning followed by an inhibited acid pickle descaling operation. The cleaned components were assembled and then placed within a glass tube plenum chamber. Aluminum end caps were used to close the tube ends and the ends of the plenum chamber, and the assembly was purged with dried argon gas. The first brazing trial was conducted with a seven-turn induction heating coil



SLEEVE MATERIAL	TUBE OD	SLEEVE DIMENSIONS										
		A	B	C	D	E	F	G	H	J	K	L
AISI Type 347 Stainless Steel	1	1.500 ±.005	0.375 ±.010	1.255 ±.005	1.082 +.005 −.000	1.002 +.001 −.000	1.0005 +.001 −.000	1.055 +.005 −.000	0.550 ±.005	0.195 ±.005	0.100 +.005 −.000	0.6875 +.005 −.000
	3	3.335 ±.005	0.875 ±.010	3.720 +.010 −.000	3.130 ±.010	3.003 +.001 −.000	3.001 +.001 −.000	3.200 +.005 −.000	1.200 ±.005	0.245 ±.005	0.205 +.005 −.000	1.550 ±.005
AM 355 SCT Stainless Steel	1/4	0.559 ±.005	0.156 ±.010	0.400 +.005 −.000	0.321 +.005 −.000	0.254 +.001 −.000	0.251 +.001 −.000	0.276 +.005 −.000	0.223 ±.005	0.100 ±.005	0.040 +.005 −.000	0.245 +.005 −.000
	1	1.500 ±.005	0.375 ±.010	1.304 +.005 −.000	1.082 +.005 −.000	1.007 +.001 −.000	1.004 +.001 −.000	1.055 +.005 −.000	0.550 ±.005	0.195 ±.005	0.100 +.005 −.000	0.6875 +.005 −.000
Rene' 41	1/8	0.500 ±.010	0.125 ±.010	0.187 ±.005	0.158 +.005 −.000	0.128 +.001 −.000	0.128 +.001 −.000	—	—	—	—	—

TABLE XIV. DIMENSIONS OF FITTING SLEEVES.

which was made of 1/4 inch diameter copper tubing. The coil turns were evenly spaced and located so that the heat pattern covered the entire fitting sleeve length. The coil was located outside the inert atmosphere plenum chamber tube. With this arrangement the fitting sleeve quickly heated to brazing temperature, but the three-inch diameter by 0.250 inch thick wall tubing ends were heated only slightly. Because of this heating differential and the resulting greater expansion of the fitting sleeve, a large cap developed between the fitting sleeve and the tubing. The braze alloy melted and drained out the end of the fitting sleeve because of this excessive gap.

A modified induction heating coil was then prepared. The two turns at each end of the coil were spread apart from the three center turns. When the coil was placed in brazing position, the two turns at each end of the coil were located over the three-inch diameter tubes just beyond the ends of the fitting sleeve. All turns of this coil were wound to the same diameter and, again, the coil was located outside the glass tube plenum chamber. Heating of the joint was somewhat more uniform with this coil, but there still was an undesirable temperature differential with the tubes being colder than the fitting sleeve because of poor inductive coupling of the end coil turns to the three-inch diameter tubing.

A new induction coil was then made which had the end coil turns wound to a smaller diameter than the three center turns, as shown in Figure 45. This new induction coil was designed to equalize the inductive coupling to the tube sections and to the fitting sleeve, and so produce a uniform flux pattern in the several components of the joint and which would, in turn, produce a more even heating of the tubes and the fitting sleeve.

A feasibility study of the heating effectiveness of this close-coupled induction coil was conducted. The glass plenum chamber was replaced with a plastic bag. The plastic was held away from the heated space by wire spacers and also by the slight positive pressure of the contained argon atmosphere. This set-up is shown in Figure 46. The tubes and the fitting sleeve were brought to brazing temperature in an acceptable manner, as shown in the time-temperature graph of Figure 47. These results indicate that a close coupling with 3/16 inch to 1/4 inch gap between the outside diameter of the tubing and fitting sleeve and the inside diameter of the turns of the induction coil produces effective uniform heating of both the fitting sleeve and the three-inch diameter type 347 stainless steel tubing. No further work under this program was accomplished with the joint after the above demonstration of the feasibility of braze joining this size tubing and the effectiveness of the joint design and the induction heating cycle to obtain uniform heating of the tubing and fitting sleeve.

Brazing of AM 350 Stainless Steel Tubing

The only brazing alloy which was considered for use with AM 350 stainless steel tubing during the initial brazing alloy evaluation work was 72Ag-28Cu-Li. The selection of this alloy was based on the satisfactory results which have been obtained by NAA in brazing tube joints for the XB-70 aircraft high pressure hydraulic system, Reference (51).

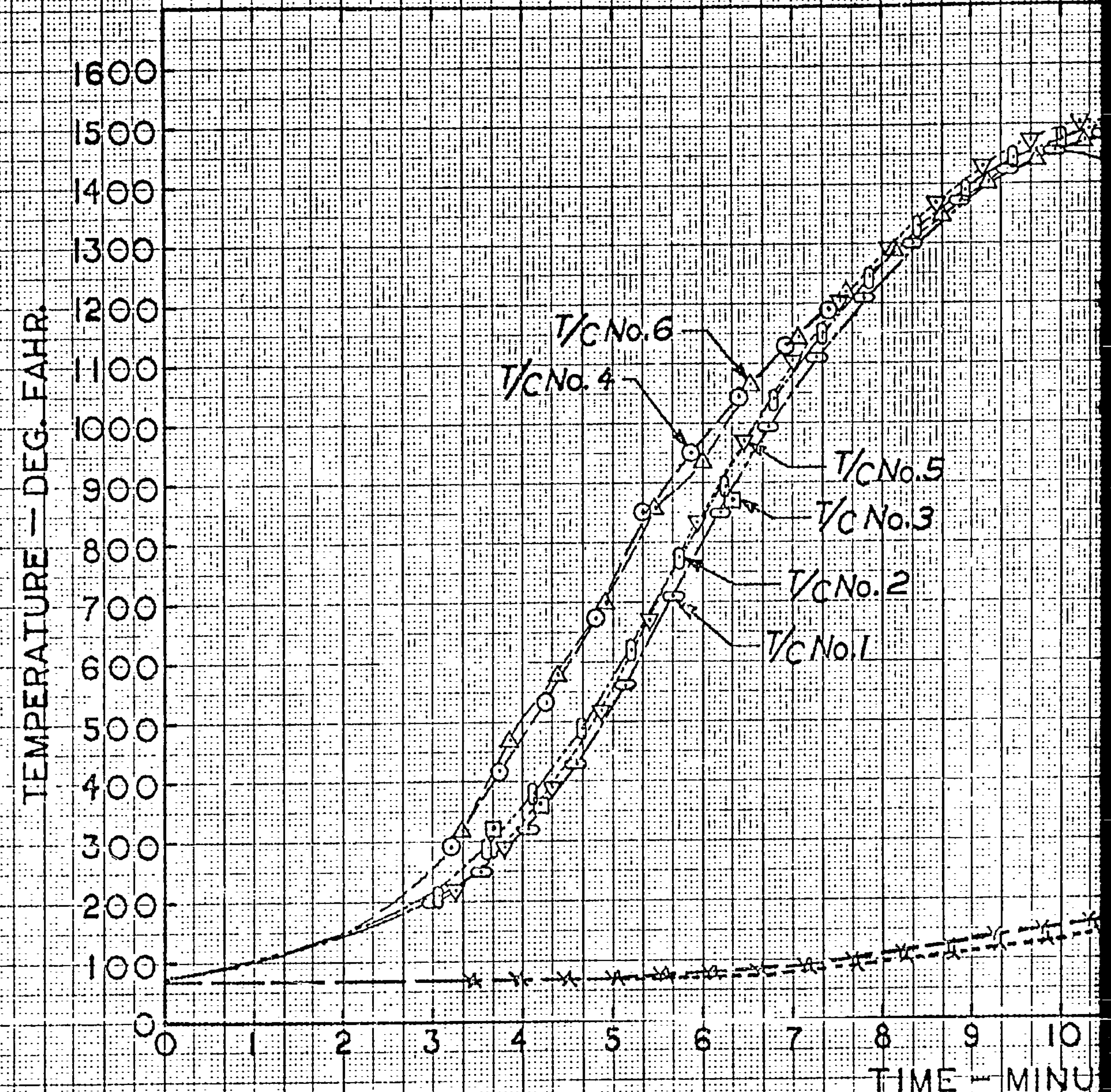
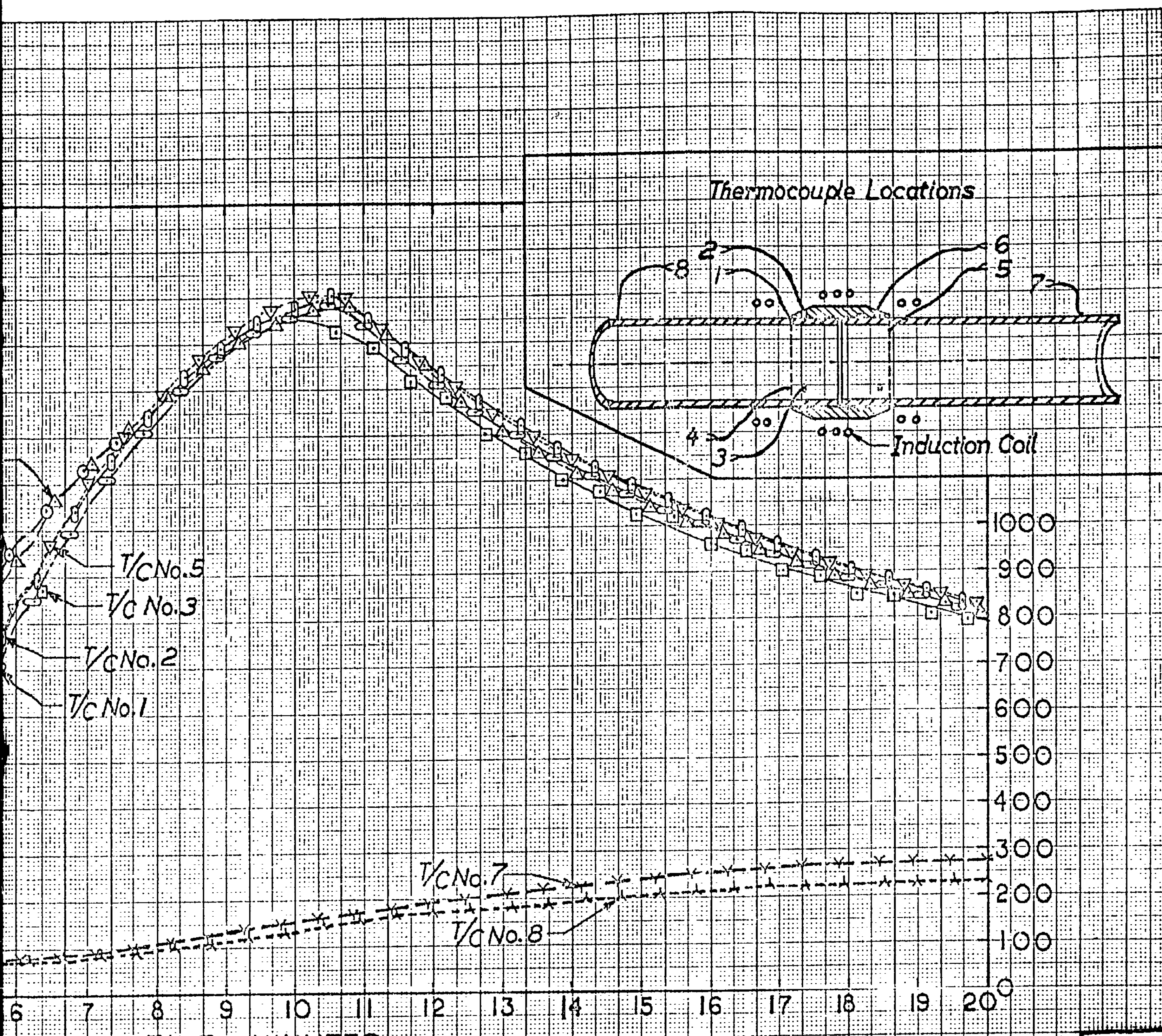


FIGURE 47. TEMPERATURE CYC
AISI TYPE 347 STAIN



EMPERATURE CYCLE FOR 3 INCH DIAMETER
1 TYPE 347 STAINLESS STEEL BRAZED FITTING.

2

The 72Ag-28Cu-Li braze alloy wetted and flowed very well in the AM 350 stainless steel tube joints. However, the first experimental joints brazed with the AM 350 tubing were considerably below the normal NAA production brazing quality level. They had approximately 30 percent voids. Examination of the test joints showed that the clearance between the tubes and the fitting sleeve had increased during the brazing operation. The dimensional tolerances of the components of AM 350 tube joints had been established with the expectation that the AM 355 fitting sleeve would contract slightly during the brazing cycle. The AM 355 stainless steel fitting sleeve used in the initial test joints was not in the required heat treat condition, and as a result the fitting sleeve underwent dimensional growth rather than the expected shrinkage. This problem was eliminated in subsequent tests by having the tubing and fitting sleeve materials carefully inspected to insure that they were in the proper heat treat condition. The tubing should be in either the CRT or SCT condition, and the sleeve should be in the SCT condition.

The block shear strength of joints brazed with the 72Ag-28Cu-Li alloy, as shown in Figure 4, page 24, is expected to be 22,000 psi at room temperature, 20,000 psi at 200 F, and 12,000 psi at 600 F, References (18) and (72). The stress analysis which was made during the design of the AM 355 stainless steel fitting sleeves for the AM 350 tubing qualification test specimens determined that, because of the given strength levels for the 72Ag-28Cu-Li braze alloy, the length of braze joint required to provide sufficient shear strength in the braze alloy of the joint would cause the overall length of the fitting sleeve to be considerably greater than the desired 1.5 times the outside diameter of the tubing. The long length of the fitting sleeve is necessary when the silver-base alloy is used with the AM 350 tubing because of the high design pressures required. The maximum system operating pressure is specified as 10,000 psi, therefore, the joints must be designed for a proof pressure of 15,000 psi and a burst pressure of 20,000 psi, both at 600 F temperature. In addition, the joint must be designed to withstand repeated bending stresses (which impose tensile stresses on the joint, or shear stress in the braze alloy), the maximum bending stress being equivalent to 75 percent of the yield strength of the tubing material.

In order to satisfy the qualification test requirements and still keep the length of the fitting sleeve to not more than the 1.5 times the tubing diameter requested by the Air Force, it is necessary to use a brazing alloy which has a higher shear strength at 600 F than does the silver-base 72Ag-28Cu-Li alloy. The braze alloy that was chosen was a gold-base alloy having the composition 81.7% Au+18% Ni+0.3% Li, which is similar to the 82Au-18Ni alloy with a lithium addition. The 82Au-18Ni alloy, as shown in Figure 4, page 24, has a block shear design strength at 600 F of 60,000 psi. This is five times as strong as the 12,000 psi block shear strength at 600 F of the 72Ag-28Cu-Li silver-base braze alloy.

The 81.7Au-18Ni-0.3Li braze alloy exhibited excellent wetting and flow properties in the manufacture of the AM 350 stainless steel tubing specimens for the qualification tests, and produced satisfactory brazed joints. This alloy was used as a wire preformed ring. The sleeve fitting was similar in design to that used with the type 321 and type 347 stainless steel tubing

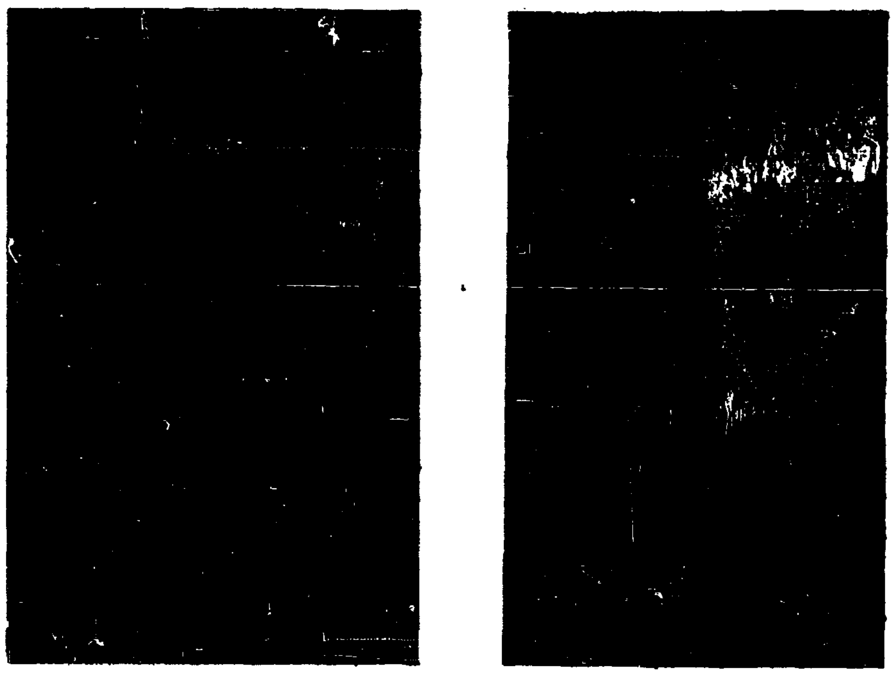
described previously. The AM 355 fitting sleeves were machined to a 0.002 inch slip fit to the outside diameter of the AM 350 tubing. The AM 355 fitting sleeve undergoes a metallurgical transformation when it is heated to the brazing temperature. This transformation causes a shrinkage of the inside diameter of the fitting sleeve. Therefore, a controlled capillary gap must be machined into the fitting sleeve in order to maintain the proper clearance.

The maintenance of a close fit between the fitting sleeve and the tubing during the entire brazing cycle is very important if a strong, void-free joint is to be obtained. The use of a fitting sleeve material such as AM 355, which undergoes a dimensional contraction or shrinkage because of a metallurgical change during the brazing cycle is very conducive to obtaining the proper sleeve-to tube fit, preventing leakage or drop-out of the brazing alloys and providing a suitable capillary thickness for optimum braze alloy flow.

Preliminary Studies for Brazing Rene' 41 Alloy

The Au-Ni-Cr, Au-Ni-Cu, and Au-Ni gold-base alloys and the 60Pd-40Ni-0.3Li alloy showed the best wetting and flow properties with Rene' 41 base metal. These braze alloys were then tested for block shear strength as previously described in Section 2, MATERIAL SELECTION, of this report. Besides strength data, other information about the brazing characteristics of the candidate brazing alloys is also determined during the block shear tests. The extent of melting, wettability and flow of the brazing alloys can be observed from examination of the sheared surfaces of the specimens after testing. The effectiveness of various cleaning procedures can also be evaluated in this manner. Finally, metallurgical examination of the specimens can be performed to determine the extent and type of diffusion or other reaction of the braze alloy with the basis material, References (30), (31), (35), (38), (45), (46), and (71). The braze alloys used to make the Rene' 41 block shear specimens were in the form of foil. The gold-base braze alloys were .002 inch thick foil, and the palladium-nickel alloy was .005 inch thick foil. The composition, melting temperature, and brazing temperature of these and other candidate brazing alloys considered for this program are given in Table XII, page 93.

The palladium-nickel brazing alloy exhibited the best consistent wetting and flow characteristics of the braze alloys which were used to make the Rene' 41 block shear test specimens for this program. This was judged by the appearance and absence of voids in the sheared braze joint surfaces, such as the surfaces of the tested block shear specimens shown in Figures 48 and 49. The gold-base braze alloys exhibited a less consistent flow and wetting of the Rene' 41 block shear specimens, as evidenced by the presence of up to 20 percent voids in the failed braze surfaces of some of the tested specimens. The degree of void area for the gold-base braze alloy specimens is listed in Table IX, page 27. The appearance of the failed surfaces of those specimens tested at room temperature are shown in Figures 50, 51, and 52.



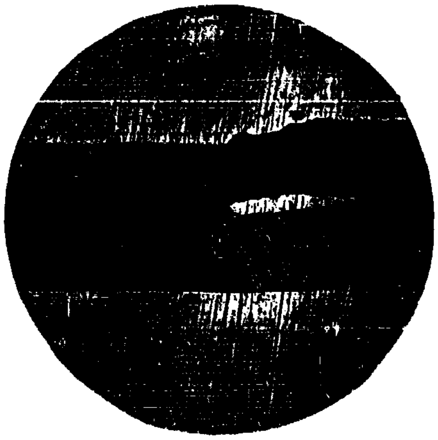
Magnification - 10 X

Specimen No. 2	Specimen No. 3
Ultimate Strength 82,828 psi	Ultimate Strength 88,656 psi

Base Material: Rene' 41
Braze Alloy: 60Pd-40Ni-0.3Li
Test Temperature: Room

FIGURE 48

APPEARANCE OF SHEARED BRAZE SURFACES
AFTER BLOCK SHEAR TEST OF 60Pd-40Ni-0.3Li BRAZE ALLOY
SHOWING COMPLETE "WETTING"



Magnification - 500X

Specimen No. 21
Ultimate Strength 104,545 psi

Base Material: Rene' 41
Braze Alloy: 60Pd-40Ni-0.3Li
Test Temperature: -320 F

FIGURE 49

CROSS SECTION OF SHEARED BRAZE JOINT AFTER BLOCK SHEAR TEST OF 60Pd-40Ni-0.3Li BRAZE ALLOY

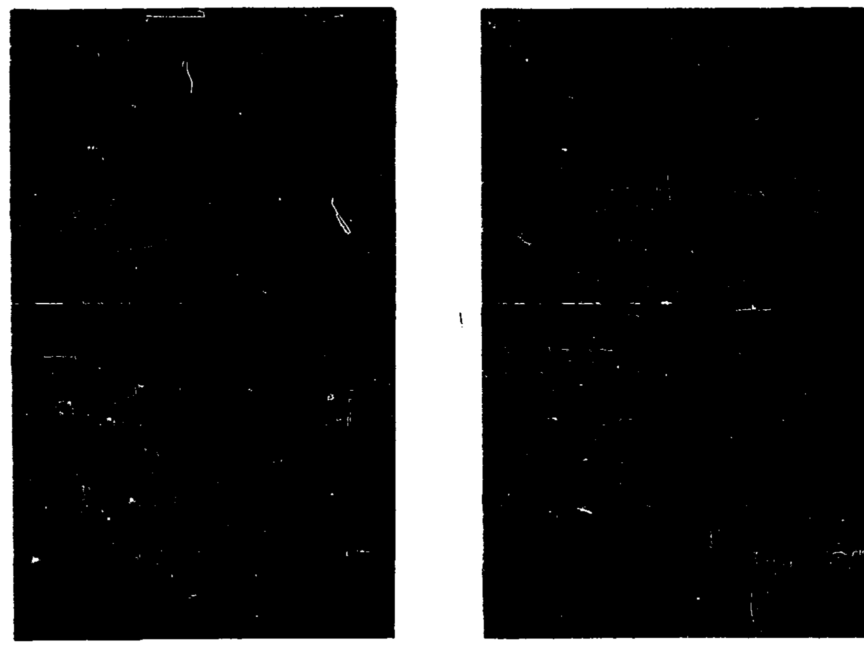
Magnification - 500X

Specimen No. 21
Ultimate Strength 104,545 psi

Base Material: Rene' 41
Braze Alloy: 60Pd-40Ni-0.3Li
Test Temperature: -320 F

FIGURE 49

CROSS SECTION OF SHEARED BRAZE JOINT AFTER BLOCK SHEAR TEST OF 60Pd-40Ni-0.3Li BRAZE ALLOY



Magnification 10X

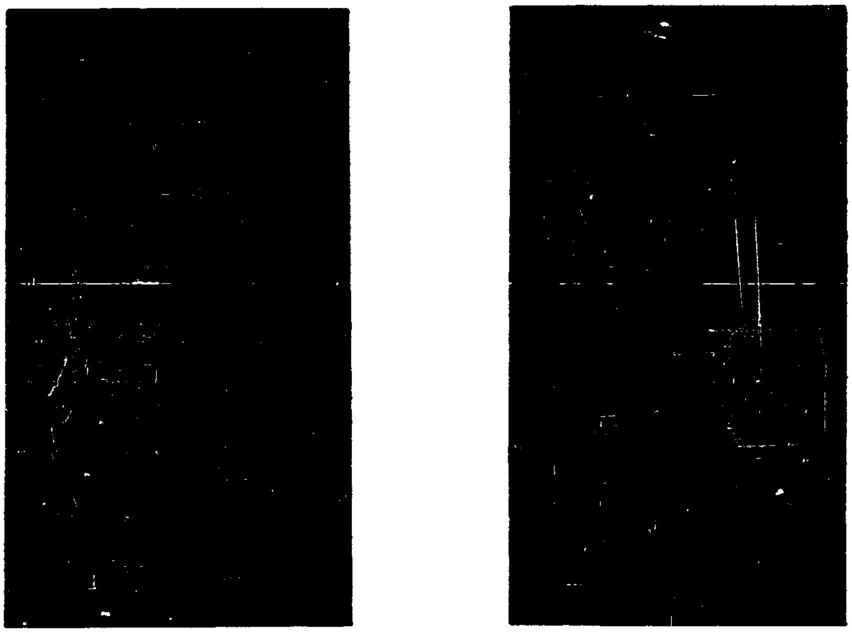
Specimen No. 7
5% voided Area
Corrected Strength 74,876 psi

Specimen No. 8
20% Voided Area
Corrected Strength 78,541 psi

Base Material: Rene' 41
Braze Alloy: 72Au-22Ni-6Cr
Test Temperature: Room

FIGURE 50

APPEARANCE OF SHEARED BRAZE SURFACES
AFTER BLOCK SHEAR TEST OF 72Au-22Ni-6Cr BRAZE ALLOY



Magnification 10 X

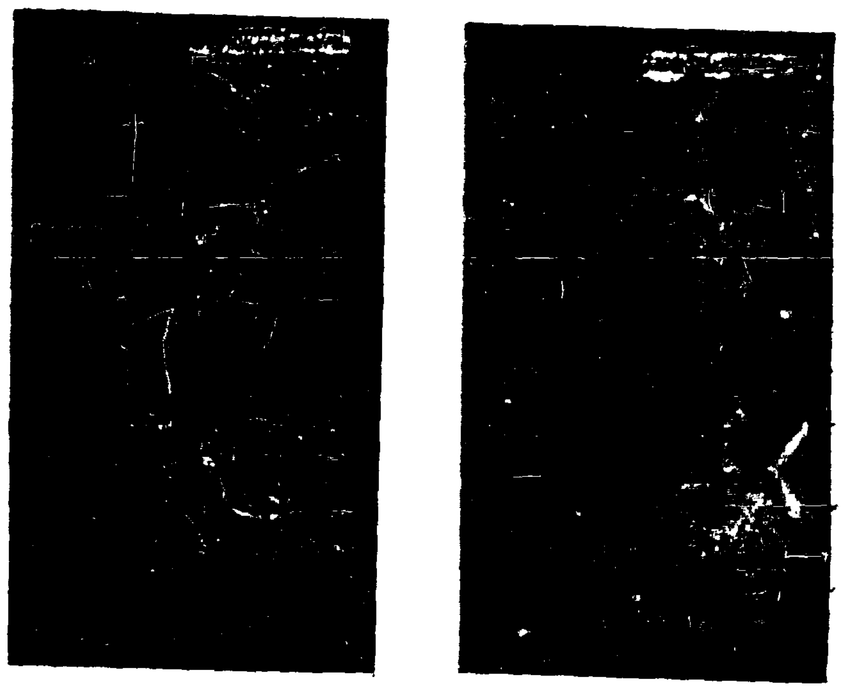
Specimen No. 4
Ultimate Strength 49,245 psi

Specimen No. 5
5% Voided Area
Corrected Strength 45,194 psi

Base Material: Rene'41
Braze Alloy: 35Au-62Cu-3Ni
Test Temperature: Room

FIGURE 51

APPEARANCE OF SHEARED BRAZE SURFACES
AFTER BLOCK SHEAR TEST OF 35Au-62Cu-3Ni BRAZE ALLOY



Magnification 10X

Specimen No. 11
10% Voided Area
Corrected Strength
51,447 psi

Specimen No. 12
5% Voided Area
Corrected Strength
63,957 psi

Base Material: Rene' 41
Braze Alloy: 82Au-18Ni
Test Temperature: Room

FIGURE 52

APPEARANCE OF SHEARED BRAZE SURFACES
AFTER BLOCK SHEAR TEST OF 82Au-18Ni BRAZE ALLOY

The two Ni-Cr-B brazing alloys did not show satisfactory wetting and flow characteristics with Rene' 41 material. These alloys are available only in powder form, and were mixed with a binder for application. Powder type brazing alloys frequently are contaminated with oxides and other impurities. Examination of the braze alloy wetting and flow specimens indicated that the binder used in these powder alloys and probably the self-contained oxides adversely affected the wetting and flow characteristics. In addition, the powder form of these alloys is not adaptable to "in-place" brazing of tube joints, and the alloys are brittle when prepared as preform rings. Therefore, block shear tests were not conducted for the Ni-Cr-B alloys and they were not investigated further.

The gold-base 72Au-22Ni-6Cr and 82Au-18Ni alloys and the palladium-nickel-lithium alloy were selected on the basis of the wetting, flow, and block shear test results for further evaluation for use in brazing Rene' 41 alloy tube joints.

The form in which each brazing alloy was used was governed first by the forms in which it was available and secondly by ease of handling or method of application. The 82Au-18Ni alloy was used as a preformed ring which was preplaced within a grooved fitting sleeve. The 72Au-22Ni-6Cr alloy was not available as a preformed ring, but was used in the form of a wire loop which was placed inside the fitting sleeve between the two butting tube ends. These two designs of fitting sleeve assemblies are shown in Figure 44, page 97 . The palladium-nickel-lithium alloy was prepared in the form of thin foil. This alloy was pre-wrapped around the outside of the tube ends, and then a straight-through bore (ungrooved) fitting sleeve was pressed over the braze-alloy-wrapped tube ends.

The joint clearance or diametrical gap between the outside of the tube and the inside of the fitting sleeve for the preliminary Rene' 41 tube joint specimens was 0.003 inch for the gold-base alloys, and a clearance of 0.003 to 0.004 inch for the palladium-nickel-lithium alloy depending on the thickness of the wrap of brazing alloy foil.

Brazing Rene' 41 Tube Joints With Pd-Ni-Li Alloy

The 60Pd-40Ni-0.3Li brazing alloy had shown promise during initial evaluation work with the wetting and block shear specimens. Excellent block shear strength was attained at all temperatures from sub-zero to 1500 F. But, difficulties were encountered during the preliminary attempts to braze Rene' 41 tube joints. The high melting temperature of this alloy (2100 F) required a brazing temperature of 2150 F. The 60Pd-40Ni-0.3Li alloy is available commercially only in the powder form. The alloy used for the tests under this program was prepared in the NAA Laboratory by vacuum induction melting, and was then rolled to 0.003 inch thick foil. The first melt of this alloy was used for the preliminary tests and produced the excellent results. Two successive attempts to reproduce this alloy were unsuccessful. Both trials resulted in alloy with melting points above 2150 F. When these lots of alloy were used to braze tube joints, brazing temperatures of 2200 F or higher were required, which caused incipient melting and deformation of the Rene' 41 tubes and fitting sleeve.

Inasmuch as the shear strength of the gold-base alloys was determined to be adequate for the Rene' 41 tube system requirements under this program, the 60Pd-40Ni-0.3Li alloy was dropped as a candidate braze alloy for this program. The problems encountered were probably caused by variations in the lithium content, which has a great effect on the melting point of the alloy. The 60Pd-40Ni-0.3Li alloy lot first made had good wetting and flow characteristics with Rene' 41. It was not necessary to nickel plate the Rene' 41 surfaces in order to obtain satisfactory wetting, as was the case with the gold-base alloys. The strength characteristics of the block shear specimens at 1500 F were excellent. This alloy should prove satisfactory for use with other high-strength high-temperature tubing materials, such as Haynes alloy HS-25. Further development of this brazing alloy is, therefore, recommended under a separate development program.

Brazing Rene' 41 Tube Joints With Au-Ni Alloys

Of the three gold-base brazing alloys selected for evaluation with Rene' 41 tubing during the initial investigation, only the Au-Ni-Cr and the Au-Ni alloys produced satisfactory brazed tube joints. Both of these brazing alloys produced joints that were 90 to 95 percent void free. On the basis of the shear strength data shown in Figures 3 and 4, pages 23 and 24, both brazing alloys can be expected to produce joints that would pass the burst test requirements at 1500 F. The 82Au-18Ni alloy is readily available as a preform ring while the Au-Ni-Cr alloy is not. Preform rings of brazing alloy have the advantage of being easier to use and produce more reproducible quality joints. Therefore, because of its availability as a preform ring, the 82Au-18Ni alloy was selected at the end of the initial evaluation work as the recommended alloy for brazing Rene' 41 tube joints.

At the start of the brazing parameter development work, difficulty had been encountered in obtaining satisfactory flow of the gold-base brazing alloys along the Rene'41 tube joint capillary. This difficulty was believed to result from the presence in Rene' 41 alloy of elements which form oxides on the tube and sleeve surfaces and inhibit wetting and flow of the brazing alloy. This problem was eliminated by nickel plating the Rene' 41 alloy tube and fitting sleeve surfaces to be brazed. The gold-base brazing alloys were able to wet the nickel plating and flow easily through the joint capillary. Excellent joints, such as the one shown in Figure 53, were obtained by this technique.

Brazing Rene' 41 Tube Joints With Au-Ni-Li and Au-Ni-Pd Alloys

The necessity to nickel plate the Rene' 41 tube and fitting sleeve surfaces in order to obtain good quality brazed joints was undesirable for production work or for repairs in the field. Therefore, additional studies were made to find brazing alloys which could be used with bare Rene' 41 surfaces. Gold-base brazing alloys containing lithium or palladium were procured. Both of these elements are known to promote braze alloy flow and to improve the wetting characteristics. An alloy of the composition 81.7% Au+18% Ni+0.3% Li and also an alloy of the composition 70%Au+22%Ni+8% Pd were tested. Both alloys were shown to produce excellent quality brazed joints without the use of nickel plate on the Rene' 41 tube surfaces.

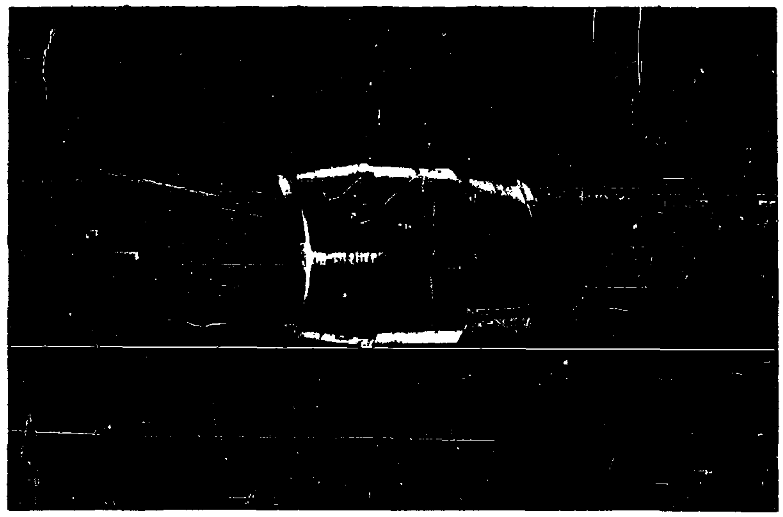


Figure 53

TYPICAL BRAZED TUBE JOINT PRODUCED WITH RENE' 41.
SURFACES TO BE BRAZED WERE NICKEL PLATED.

The lithium in the one alloy acts as a volatile flux to reduce any oxides present on the surface to be brazed and also reduces the surface tension of the brazing alloy, thereby increasing its fluidity and ability to wet the surfaces to be joined. The improved wetting and flow of the gold-nickel alloy containing palladium also results from a decrease of surface tension produced by the palladium, Reference (73). The improved strength of the palladium containing braze alloys is considered to be the result of the known solid solution strengthing action of palladium on gold and nickel alloys, Reference (20).

The 1/8 inch diameter Rene' 41 alloy tube qualification test specimens were brazed with the Au-Ni-Li alloy. The shear strength of this alloy at 1500 F is approximately 4,000 psi, as shown in Figure 4, page 24. This strength was determined to be adequate for the 1/8 inch diameter tube joints because of the proportionately long length of braze area which is incorporated in the 1/2 inch long fitting sleeves. The fitting sleeve length was chosen to provide for ease of handling and proper alignment of the tubing to be joined. It is recommended that the minimum length of fitting sleeves be not less than 1/2 inch, even for the smallest diameter tubing.

The 1/8 inch diameter Rene' 41 alloy qualification test specimens were brazed using a straight-through bore fitting sleeve. A single ring of brazing alloy was preplaced inside the fitting sleeve between the tube ends. The joint clearance was held between 0.001 and 0.002 inch.

The temperature-strength requirements for the one-inch diameter Rene' 41 tubing joints require the use of a stronger brazing alloy than the gold-nickel-lithium alloy. The gold-nickel-palladium brazing alloy was planned to be used for these joints. This alloy is reported to have a block shear strength at 1500 F of 30,000 psi, Reference (74), which is much stronger than the 4000 psi strength of the gold-nickel-lithium alloy, Figure 4, page 24.

5.2 BRAZING PARAMETERS

The following brazing parameters are considered essential for successful tube brazing. These parameters were studied in detail for each of the tubing materials considered for use in this program.

(1) Cleaning
(2) Atmosphere control
(3) Fitting sleeve design
(4) Induction heating coil design
(5) Heating rate and uniformity of heating

Three other factors also considered important were the form of the brazing alloy, the fitting sleeve design, the tube sizing, and the power requirements for brazing.

Several of these parameters were relatively independent of the material being brazed. These independent parameters were the cleaning, atmosphere

control, heating rate, and the power requirements. There was little difference in these parameters whether the material being brazed was Rene' 41, AM 350, or type 347 stainless steel. These independent parameters will be discussed in the following paragraphs.

The other parameters were dependent upon the brazing alloy and/or the material being joined. These dependent parameters are the fitting sleeve design, including the brazing alloy form and the joint clearance or diametrical spacing between the sleeve and tube, and the induction heating work coil design. The dependent parameters are also discussed below.

5.3 INDEPENDENT BRAZING PARAMETERS

Cleaning

The same procedure for pre-braze cleaning was used for all three of the tubing system materials: Rene' 41 alloy, AISI type 347 and AM 350 stainless steels. This cleaning procedure, which had been developed by NAA for tube brazing, Reference (75), and was found to be entirely satisfactory for use in tube brazing for this program, was as follows:

(1) Alkaline clean by immersion Vitro-Klene (Turco Products), with Turco No. 4215 additive, for 15 to 20 minutes at a bath temperature of 170 F to 200 F.

(2) Rinse in demineralized water.

(3) Pickle in inhibited nitric acid (7 to 9 percent HNO_3 plus 6 to 8 percent Turco 4104) at room temperature for 10 minutes.

(4) Rinse in demineralized water.

(5) Rapid air dry.

(6) MEK wipe prior to assembly.

Atmosphere Control

All joints were brazed in dried argon gas. A pyrex glass tube, closed at each end by stainless steel or aluminum fittings, was used as a plenum chamber to retain the argon gas around the joint. This tube also aided in positioning the joint assembly in the induction coil. A typical tube joint assembly with a glass plenum chamber set up for brazing is shown in Figure 54. Disassembled end fittings, pyrex glass tube plenum chambers, and various sizes of induction coils are shown in Figure 55.

Dried argon gas was introduced into the plenum chamber through one of the end fittings and flowed between the metal tube and the pyrex tube, as indicated on Figure 56. Dried argon gas was also flowed through the inside of the metal tube. In this way all surfaces of the joint assembly to be brazed were in an argon atmosphere. Incoming gas flows were balanced so the pressure was approximately equal on the inside and outside of the

Figure 54. Set-up for Brazing One Inch Diameter AISI Type 347 Stainless Steel Tube Joint

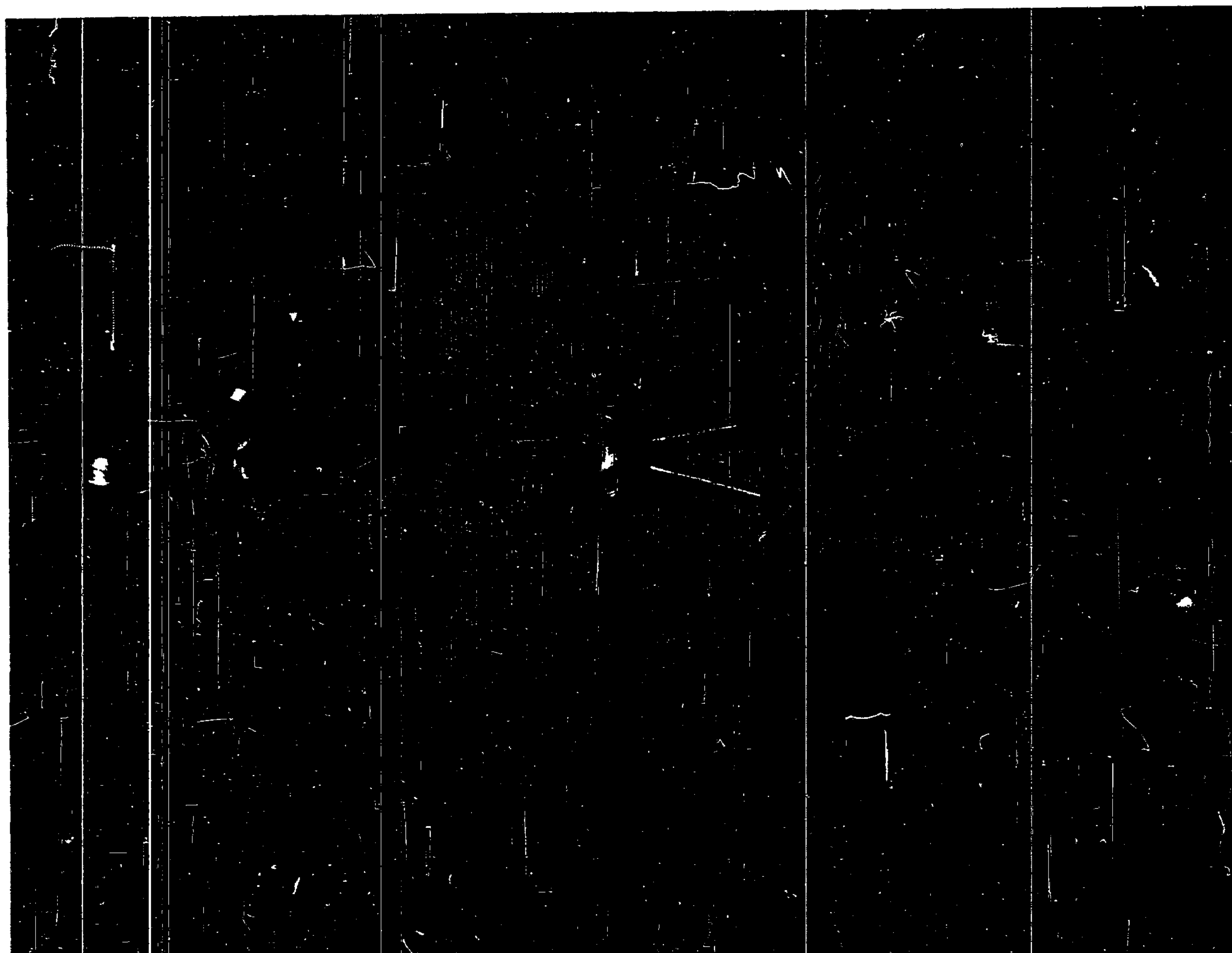


Figure 55. Induction Brazing Plenum Chamber and End Fittings (Disassembled)

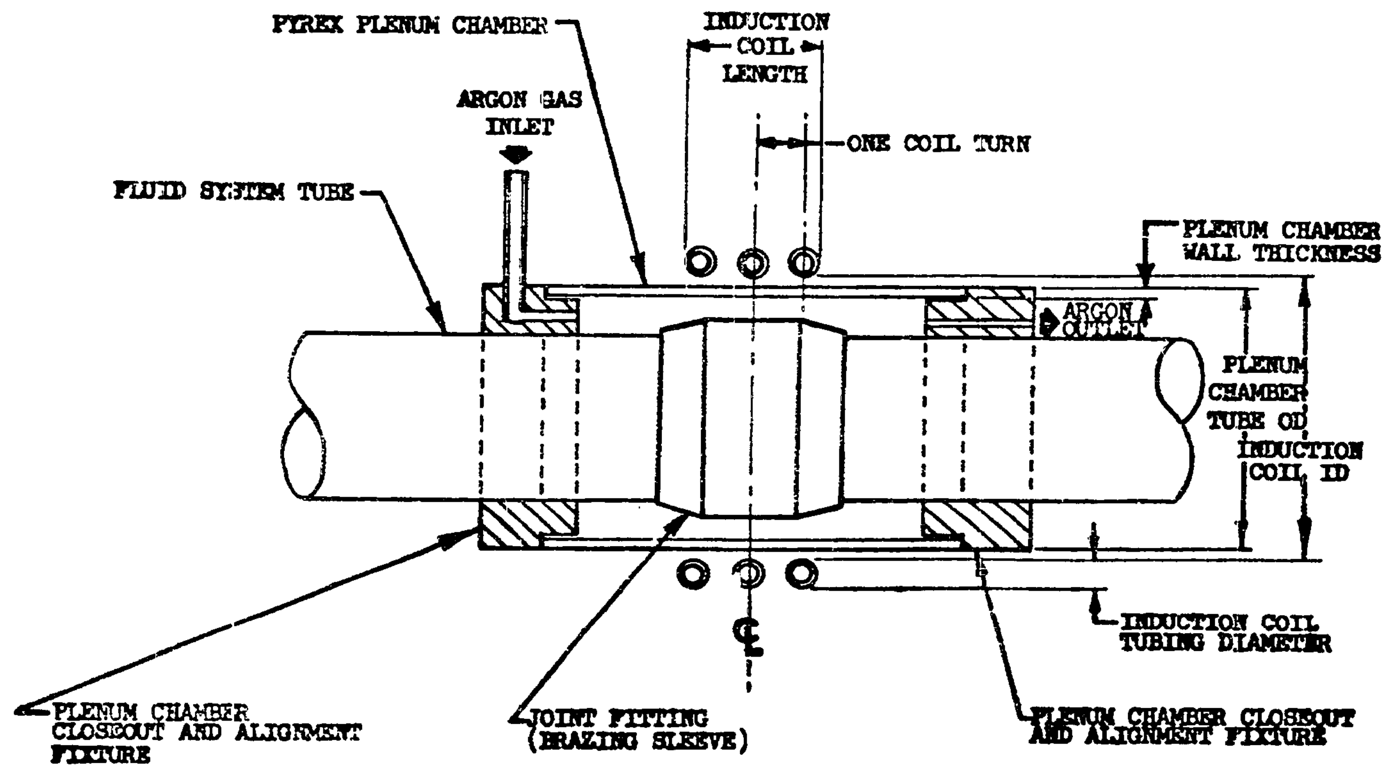


Figure 56. Schematic of Braze Tube Joining Tooling Set-Up.

tube joint assembly. If the gas flow pressures were not maintained equal there was a tendency for the argon gas to pass through the molten brazing alloy, causing voids in the brazed joints or expelling the molten brazing alloy from the joint capillary.

An internal inert gas atmosphere purge is desirable to obtain high quality brazed tube joints by preventing oxidation or scaling of the inner surfaces of the tubing and possible contamination of the joint surfaces to be brazed. If joints are to be brazed in Rene' 41 alloy tubing it is important to protect the joint surfaces from all possible contamination and an internal purge is considered very necessary.

The inert gas used for the purge and brazing cycles must be extremely free from traces of moisture. A continuous gas flow is maintained during the braze cycle to sweep off any adsorbed gases which may be released from the metal surfaces and to prevent possible leakage of air into the plenum chamber. If even small amounts of water were present in the gas, the continuous flow would introduce enough moisture to create a serious contamination problem. In order to prevent this a specially built drying train was used to ensure that the argon gas was dried to less than ten parts per million of moisture before the gas was passed through the brazing apparatus, Reference (76). In addition, low flow rates of the dried argon gas were used during brazing to further minimize the possibility of introducing traces of moisture with the argon. The argon gas flow rates were controlled to prevent air from entering the plenum chamber and contaminating the enclosed joint assembly during the brazing cycle and, particularly, when the argon atmosphere in the plenum chamber contracted in volume during rapid cooling of the system after brazing.

Power Requirements and Heating Rate

Three induction heating units were used during this program for brazing the various test specimens. They were a 30 Kw, 250 Kc Ther-Monic unit; a 2-1/2 Kw, 450 Kc Lepel unit; and a 1-1/2 Kw, 450 Kc Lepel unit. The 30 Kw Ther-Monic unit was used to braze the large and intermediate size tube joints, and can be expected to be required for all tubing joints two inches in diameter and larger. The 2-1/2 Kw Lepel unit and the 30 Kw Ther-Monic unit were both used for brazing the 1/2 inch and 3/4 inch diameter tube joints. The 1-1/2 Kw Lepel unit was used for brazing the small diameter joints, such as the 1/8 inch and 1/4 inch diameter type 321 and AM 350 stainless steel tube joints, as shown in Figures 57 and 58, respectively. All three of the induction heating units were found to be satisfactory heating sources for the tube joints brazed.

The power settings of the induction machines were initially kept sufficiently low to insure uniform heating of the tube-fitting assemblies during brazing. Slow heating rates were used during the development work in order that more time was available to observe the wetting and flow action of the brazing alloys. Heating time for these joints was between one and two minutes. The heating times used for brazing AM 350 tube joints in shop production operations frequently are of shorter duration, approximately 20 to 45 seconds. Shorter heating times on the order of the production brazing cycles were used where applicable in the manufacture of the qualification test specimens.

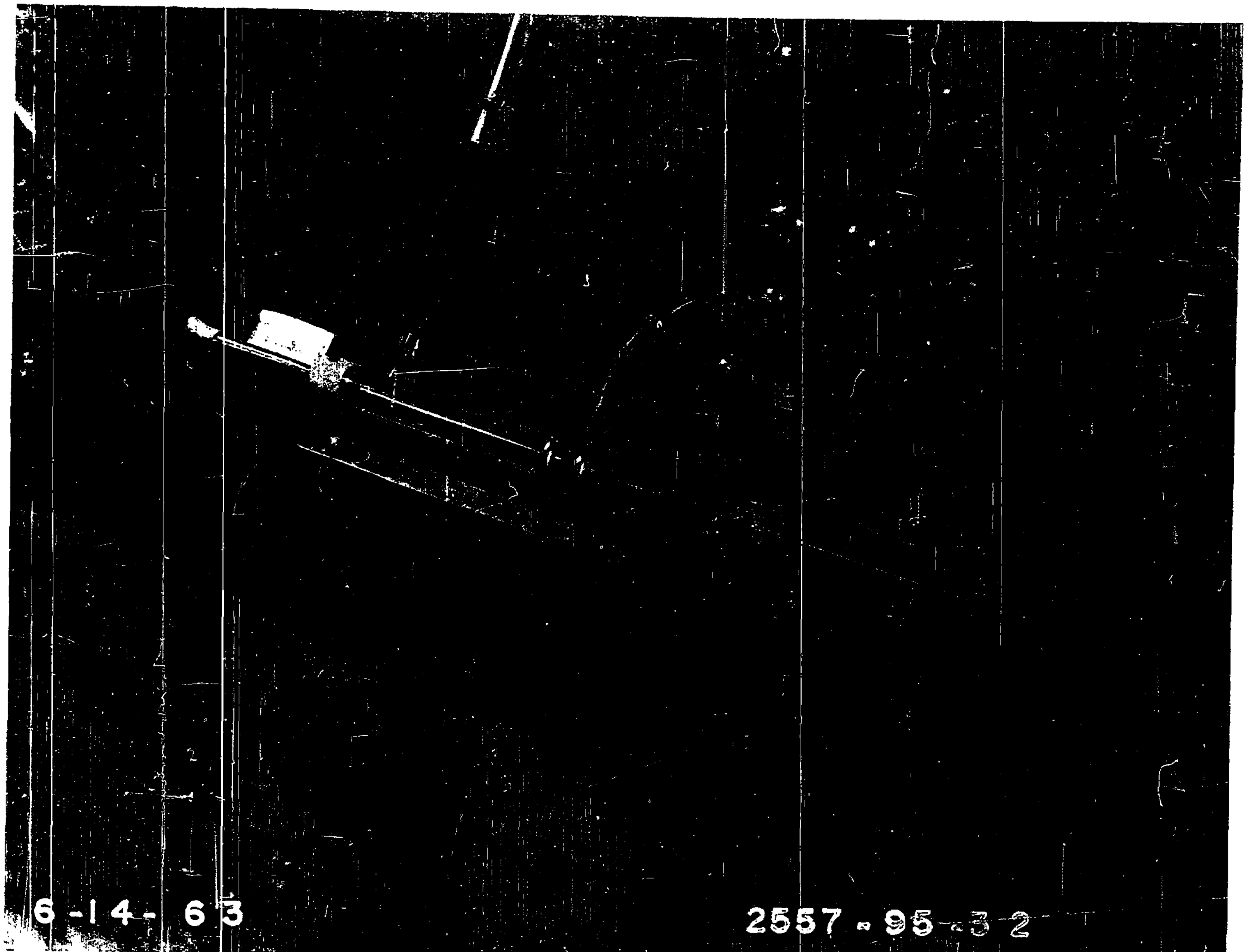


Figure 57. Set-up for Brazing 1/8 Inch Diameter René 41 Alloy Tube Joint

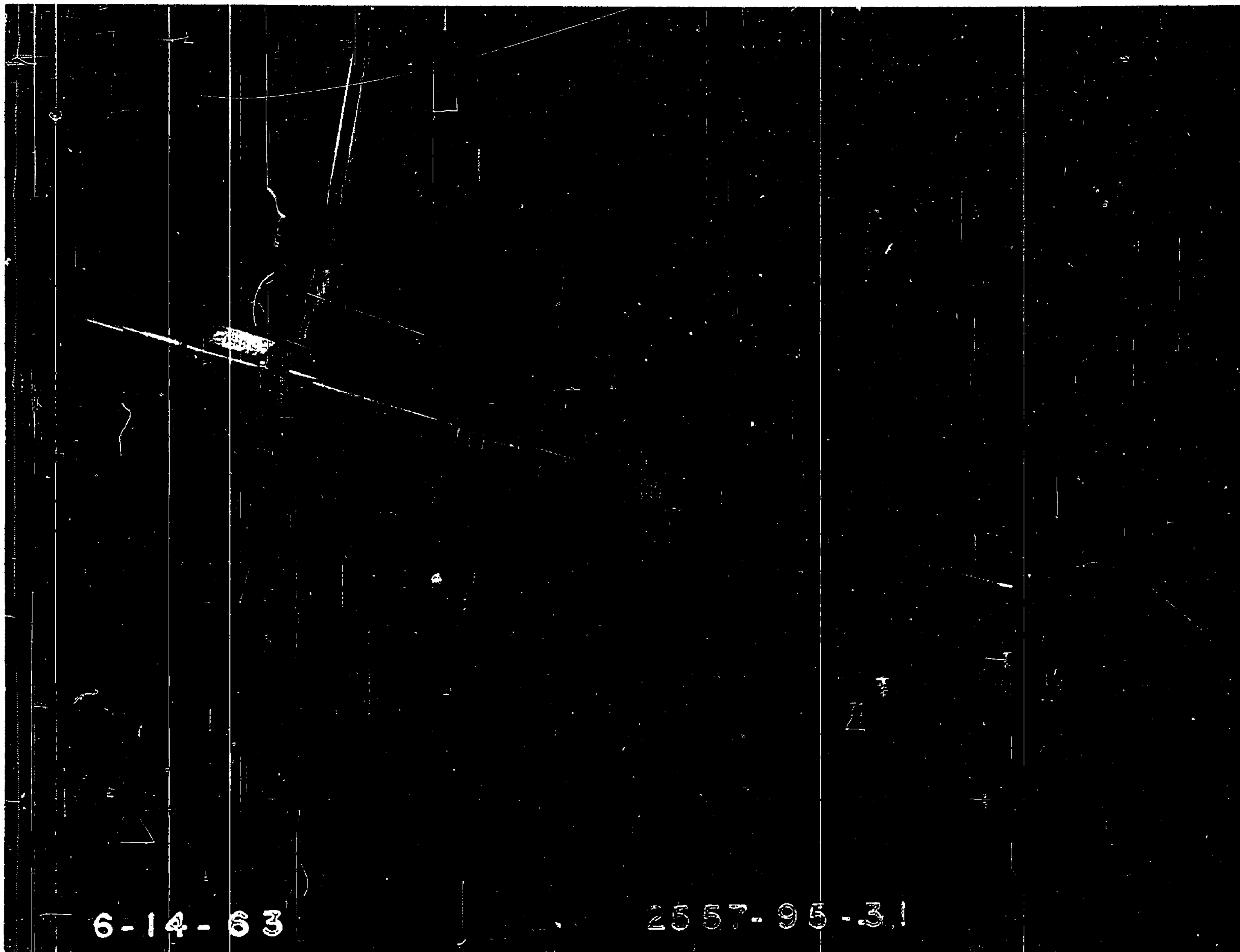


Figure 58. Set-up for Brazing 1/4 Inch Diameter AM 350 Stainless Steel Tube Joint

Table XV shows the brazing schedules used for the fabrication of the qualification test specimens.

5.4 DEPENDENT BRAZING PARAMETERS

Certain brazing parameters were previously classified as being dependent upon the brazing alloy and/or the material being joined. These were the design of the fitting sleeve including the brazing alloy form, the joint clearance or diametrical spacing, and the brazing alloy placement, and also the design of the induction heating work coil.

Design of Fitting Sleeves

The general requirements for the design of the fitting sleeves have been discussed in Section 3, STRUCTURAL ANALYSIS, paragraph 3.2 (pages 31 to 41), and also in previous paragraphs of this Section (pages 92 and 94).

Tubing Sizing

Sizing of tubing may be required in production operation to control the variation in diametrical spacing between the fitting sleeve and the tube which can occur due to the outside diameter and ovality tolerances of commercial tubing and out of tolerance conditions resulting from any tube forming operations. In order to produce high quality production-type brazed joints, tube sizing generally is necessary. Tube sizing can be accomplished satisfactorily in the hydraulic punch press; however, this method cannot be used to size tubes in place on systems during final assembly or in field repair maintenance. To accomplish tube sizing in all stages of assembly and field maintenance repair, portable high-energy tube sizing tools may be used. Tools of this type, such as the one shown in Figure 59, have been developed by the Contractor and are presently being used in the assembly of tubing systems for the XB-70 aircraft, References (77) and (78). These high-energy tube sizing tools can be used in the field under normal safety precautions. High energy to size the tubing is obtained by the expansion of gases of .22 caliber, .32 caliber, or .38 caliber charges. The tools have split dies to correct tube diameter and wall thickness.

The high-energy sizing tools are designed to size the tubing to $0.010\,^{+.003}_{-.000}$ inches above the nominal tubing diameter. Sizing tools have been used with tubing up to approximately 1-7/8 inches in diameter. Tube wall thicknesses up to .014 inch for 1/4 inch tube diameter, .072 inch for one inch diameter, and .042 inch for 1-7/8 inch diameter tubing have been sized successfully with tools of this type.

Tube sizing operations were not performed during the manufacture of the brazed specimens for use in this program. Instead, the experimental fitting sleeves were selectively fitted to the tubing.

General Induction Heating Principles

Induction heating is a process by which heat is produced in a metal which is in proximity to a rapidly varying magnetic field produced by an

TABLE XV. BRAZING PARAMETERS FOR INDUCTION BRAZE JOINING OF TUBING.

TUBING MATERIAL	AISI 347 Stainless Steel	AISI 347 Stainless Steel	AM 350 CRT Stainless Steel	AM 350 SCT Stainless Steel	Rene' 41 Alloy
TUBE SIZE Outside Diameter Wall Thickness	1.000 0.083	3.000 0.250	0.250 0.042	1.000 0.134	0.125 0.010
FITTING SLEEVE MATERIAL	AISI 347 Stainless Steel	AISI 347 Stainless Steel	AM 355 SCT Stainless Steel	AM 355 SCT Stainless Steel	Rene' 41 Alloy
COMPOSITION OF BRAZING ALLOY	71.8 Ag 28.0 Cu 0.2 Li	71.8 Ag 28.0 Cu 0.2 Li	81.7 Au 18.0 Ni 0.3 Li	81.7 Au 18.0 Ni 0.3 Li	81.7 Au 18.0 Ni 0.3 Li
BRAZING CONTROL TEMPERATURE (a)	1450 F	1500 F	1500 F	1450 F	1900 F
BRAZING HEATING TIME	47 seconds	360 seconds	15 seconds	45 seconds	45 seconds
INDUCTION HEATING MACHINE INFORMATION:					
Frequency Rated Capacity	250 Kc 30 Kw	250 Kc 30 Kw	450 Kc 2.5 Kw	250 Kc 30 Kw	450 Kc 2.5 Kw
Power Setting	20 Percent	45 Percent	75 Percent	35 Percent	65 Percent
Plate Voltage	3.5 KV	6 KV	2.7 KV	4 KV	2.3 KV
Plate Amperage	1.8 amperes	2.3 amperes	0.7 amperes	2.0 amperes	0.7 amperes

Note: (a) Control Temperature measured by thermocouple tack welded to tube OD 1/32 inch from edge of fitting sleeve.

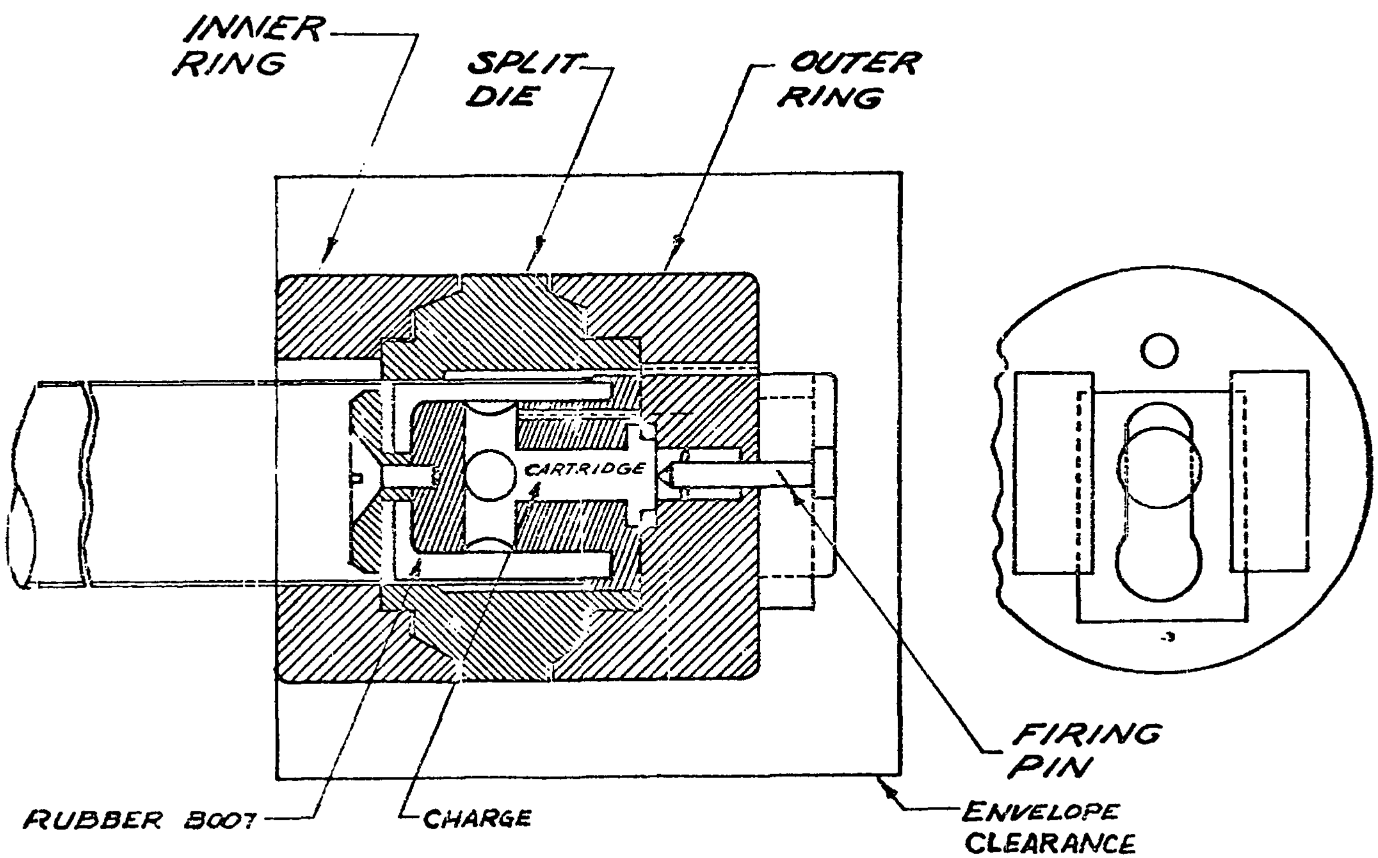


Figure 59. Portable High-Energy Tube Sizing Tool.

alternating current. The heat is caused by the resistance of the metal to the flow of eddy currents induced in the metal by the varying magnetic field, and also because of hysteresis effects on the metal. The required magnetic field is produced by conducting high frequency current through a work coil, or inductor, which acts as the primary winding of a simple transformer while the workpiece acts as a single-turn secondary. By shaping the coil properly, the heat can be localized, or spread throughout the work, as required. Heat distribution patterns can be obtained which are not possible with conventional methods of heating. The work coil may consist of a single turn, or of many turns, depending on the desired heat pattern, the work material, the current frequency, and the coupling of the coil to the work.

Frequency

The choice of frequency in induction heating depends upon the particular application. In many cases it is not critical and almost any frequency may be used. The degree to which the induced currents, and in turn the heating effect, penetrates the work is, in general, an inverse function of the frequency of the applied alternating current. Frequencies from 60 cps to approximately 450 Kc have been used for induction heating. The higher frequencies from radio frequency (RF) generators, in the approximate range from 200,000 cps to 450,000 cps, usually produce a very intense, fast, and localized heat pattern. This type of pattern is desirable for brazing thin-walled tubing of the types used in this program. A more diffuse and slower heating effect with a deeper heating penetration is produced by the lower motor-generator frequencies in the range from 1000 cps to 10,000 cps. In many cases, however, the choice of a particular frequency to be used for a given application may be determined by the characteristics of the equipment available rather than by more strictly technical considerations, Reference (79).

Coil Design

Design of the induction heating coil for tube brazing includes consideration of five variables. These variables are:

(1) Coil length
(2) Coil diameter
(3) Number of turns in coil
(4) Spacing of coil turns
(5) Size and shape of the tubing used to form the coil

The relationship of the above variables, the plenum chamber, and the joint assembly to be brazed, are shown in Figure 56, Page 118. The length of the coil is determined by the length of the area to be heated. For tube brazing the coil length is usually the length of the fitting sleeve. However, when the tubing and sleeve are high strength heat treatable materials, such as the AM350 - AM355 tubing-sleeve combination, it is frequently desired that only a portion of the fitting sleeve length be heated so that the strength properties of the tube outside the sleeve length are not reduced. In such cases the length of the coil would be

shorter than the overall length of the fitting sleeve. Variations of 1/16 to 1/8 inch in the coil length do not appear to have any detrimental effects on the brazing process or the quality of the joints. The coil length may be increased or decreased if more or less heat is required at the ends of the fitting in order to accomplish satisfactory brazing.

The inside diameter of the induction coil is normally made as small as possible consistent with the size of the plenum chamber. The spacing between the inside diameter of the induction coil and the outside of the work piece is called the "coupling" of the coil to the work. In general, the efficiency of induction heating is greatest when the coupling, or space between the coil and the work, is as close as is possible without causing the electric current to arc from the coil to the work piece. However, there are times when the coil diameter is increased in order to decrease the flux intensity and produce a more even heat input into the work. Dimensions of the pyrex plenum chamber tubes and the induction heating coils as used for several sizes of brazed tube joints during the initial part of this program are given in Table XVI. The dimensions given in this table are indicative only, inasmuch as they are dependent on the wall thickness or outside diameter of the particular fitting sleeve used to make the joint. Also, the coil diameter will be varied according to the requirements established by the joint design and the ferromagnetic characteristics of the tubing and fitting sleeve materials.

The power output, or heating efficiency, of the induction heating system is determined in great measure by the match between the electrical characteristics of the induction generator, the power transmission cable, and the coil. It is particularly important that the impedance of the transmission cable together with that of the coil-workpiece combination be properly matched to the impedance of the induction generator circuit to get maximum power transfer. To achieve this, the impedance of the induction coil can be changed somewhat by increasing or decreasing the number of turns of copper tubing which make up the coil. The length of the area of the workpiece which is to be heated is a consideration in determining the number of turns of the coil, but the matching of the electrical characteristics of the circuit is also a very important consideration. The coil length can be increased by spreading the turns farther apart, if necessary, without increasing the number of turns, although this will weaken the flux intensity and so decrease the heating effectiveness.

The workpiece resistivity and the current depth (or depth of immediate heat generation in the workpiece) are primarily determined by the physical properties of the work material and by the frequency used. Therefore, the main variables in induction heating are the coil current, the number of coil turns, and the coil length. A basic feature of the design of the induction or work coil, is the importance of the product of the number of coil turns and the magnitude of the alternating current applied to the coil.

The relationship of these various factors is shown in the following equation which is used to determine the surface power density generated in the workpiece, Reference (80).

TABLE XVI. DIMENSIONS OF TOOLING USED FOR INDUCTION BRAZING OF TUBING JOINTS.

TUBING MATERIAL TO BE BRAZED	SPECIMEN DIMENSIONS		PYREX PLENUM CHAMBER DIMENSIONS (a)		DIMENSIONS OF INDUCTION HEATING COIL				
	TUBE OD	FITTING OD	OUTSIDE DIAMETER	WALL THICKNESS	TUBE SIZE OD	NO. OF COIL TURNS	OVERALL COIL LENGTH	INSIDE DIAMETER OF COIL	COIL TURN SPACING TO
AISI Type 347 Stainless Steel	1.000	1.255	38 mm (1.496 in.)	2.0 mm (0.079 in.)	1/4	5	1-7/8	1-9/16	3/8
	3.000	3.720	108 mm (4.250 in.)	1.2 mm (0.047 in.)	1/4	7	5-1/2	4-5/16	3/4
			Plastic bag used as plenum chamber		1/4	7 (b)	5-5/8 (b)	End Coils 3-3/4 Center Coils 4-1/4	End Coils 1/2 (b) Center Coils 7/16
AM 350 CRT Stainless Steel	0.250	0.400	18 mm (0.709 in.)	1.3 mm (0.051 in.)	1/8 (c)	3	3/8	23/32	1/8
AM 350 SCT Stainless Steel	1.000	1.304	38 mm (1.496 in.)	2.0 mm (0.079 in.)	1/4	3	1-1/4	1-9/16	7/16
Rene' 41 Alloy	0.125	0.187	10 mm (0.394 in.)	1.0 mm (0.039 in.)	1/8	2	7/16	13/32	5/16

Notes: (a) Glass tubing for these plenum chambers was procured to millimeter size dimensional standards. Dimensions in inches are shown for information only.

(b) The two coil turns at each end are separated from the three center coil turns by 1-3/4 inch.

(c) Tubing flattened to an oval shape.

$$P = \frac{6.4516\ I^2\ N^2 \rho}{dL} \times 10^{-9}$$

where: P = surface power density into the work, Kw per sq. in.
I = current through work coil, amperes.
N = number of coil turns
ρ = average workpiece resistivity over the temperature rise, microhm-cm.
L = overall length of work coil, inches.
d = current depth, inches

and:

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho}{\mu f}}$$

where: μ = the magnetic permeability of the workpiece.
f = current frequency, cycles per second.

The strength of the magnetic field within the inductor or work coil is the basic factor that determines the rate of heating. For most rapid heating the work coils are designed to provide for the maximum flow of current and the closest possible coupling (distance between the coil inside diameter and the surface of the workpiece) permissible. This must take into account the work handling requirements and arcing of the electric current between the coil and the work. The above equation shows that the shorter the coil length the greater will be the surface power density in the workpiece. Therefore, it is desirable to keep the overall coil length as short as possible, Reference (81).

In practice, considerable variation exists in the design of coils. However, the coils are generally made of copper tubing because of its high heat conductivity, ease of forming, wide availability and moderate cost. Commercial copper tubing is generally used for the coils. Appreciable heating occurs in the work coil as a result of the relatively high currents used and also the high effective resistance of the coil material, due to the hysteresis effects produced by the high frequency alternating currents. Because of this heating, the work coils are generally water cooled, but air cooling is acceptable at low power.

Solenoid-type coils as shown in Figures 54, 57 and 58, pages respectively, surround the workpiece and induce external heating. Coils of this type are most efficient and should be used whenever possible. Flat pancake-type coils, internal coils, and combination coils are sometimes used for special purpose applications. Once formed, the coils can be held to a desired shape by fastening the individual turns to rigid strips of insulating material. This is particularly desirable for coils which are to be used a number of times, as in shop brazing.

Coil turns are normally spaced 1/16 inch to 3/32 inch apart. Considerable adjustment in the heat pattern is possible by changing either the spacing between coil turns or the coupling for individual turns. A single-turn coil can be made to concentrate the current into a small area,

or volume, of the work. Multi-turn coils are generally used for heating of larger areas. For an equivalent voltage applied across the coil, many more coil turns are required to produce the same heating effect with low frequency currents than when high frequency is used. However, in such cases, it is possible to use a multi-layer coil turn construction. Rectangular tubing gives the best space factor, better water cooling, and the strongest construction. Because it is more difficult to form than round tubing, rectangular tubing is used only for reusable or special coils.

The size, or diameter, of the tubing used to form the work coil, as well as the tubing shape, whether round, square, or flattened, is selected to fit the joint design, tubing and fitting sleeve material, and the induction generator which is to be used. The work coil which was used to braze the joints in the 1/4 inch diameter AM 350 stainless steel tubing was made from 1/8 inch diameter round copper tube. Round copper tubing 3/16 inch in diameter was used for the work coils with which joints were brazed in tubing 1/2 inch or more in diameter.

All tube joint brazing during the initial development work was done using hand-wound, open, water-cooled copper tube coils. The tube joint to be brazed was contained inside the glass plenum chamber. This type of arrangement is satisfactory for bench or "shop type" brazing at the work station of the induction heating unit, and it can also be used at the end of a coaxial power transmission cable for "in place" brazing at locations remote from the induction unit. The plenum chamber can be made in two pieces for ease of removal from the joint after brazing. The hand-wound copper coil is inexpensive and can be discarded after use.

Where many joints of the same size and materials are to be brazed, the work coil can be made as a reusable split-type configuration, such as is shown in Figure 60. This is a production-type tool using an air cooled coil. It is designed for ease of use in an area of limited accessibility at a distance from the induction generator. This tool is used in conjunction with semi-automatic controls and does not require a high level of skill by the using personnel, References (61) and (79). Each tool is certified and contains a thermocouple which automatically cuts off the induction generator when the joint temperature indicated is that which was obtained during certification of the tool. Such a unit is satisfactory for precision machined fitting sleeves where the wall thickness and fitting sleeve diameters are held to close tolerances, and where the nature of the materials and the size of the joint do not require particularly large amounts of heat or long heating times.

5.5 JOINT REBRAZING FEASIBILITY STUDY

A feasibility study was made to determine the problems associated with debrazing and rebrazing of joints made with the materials used in this program. The preliminary rebrazing study was conducted with a simple butt joint specimen made from Rene' 41 rectangular bar. The brazing alloys investigated were the 82 Au-18Ni alloy and the 60Pd-40Ni-0.3Li alloy. The brazing, debrazing, and rebrazing operations were performed with the apparatus shown in Figure 61.

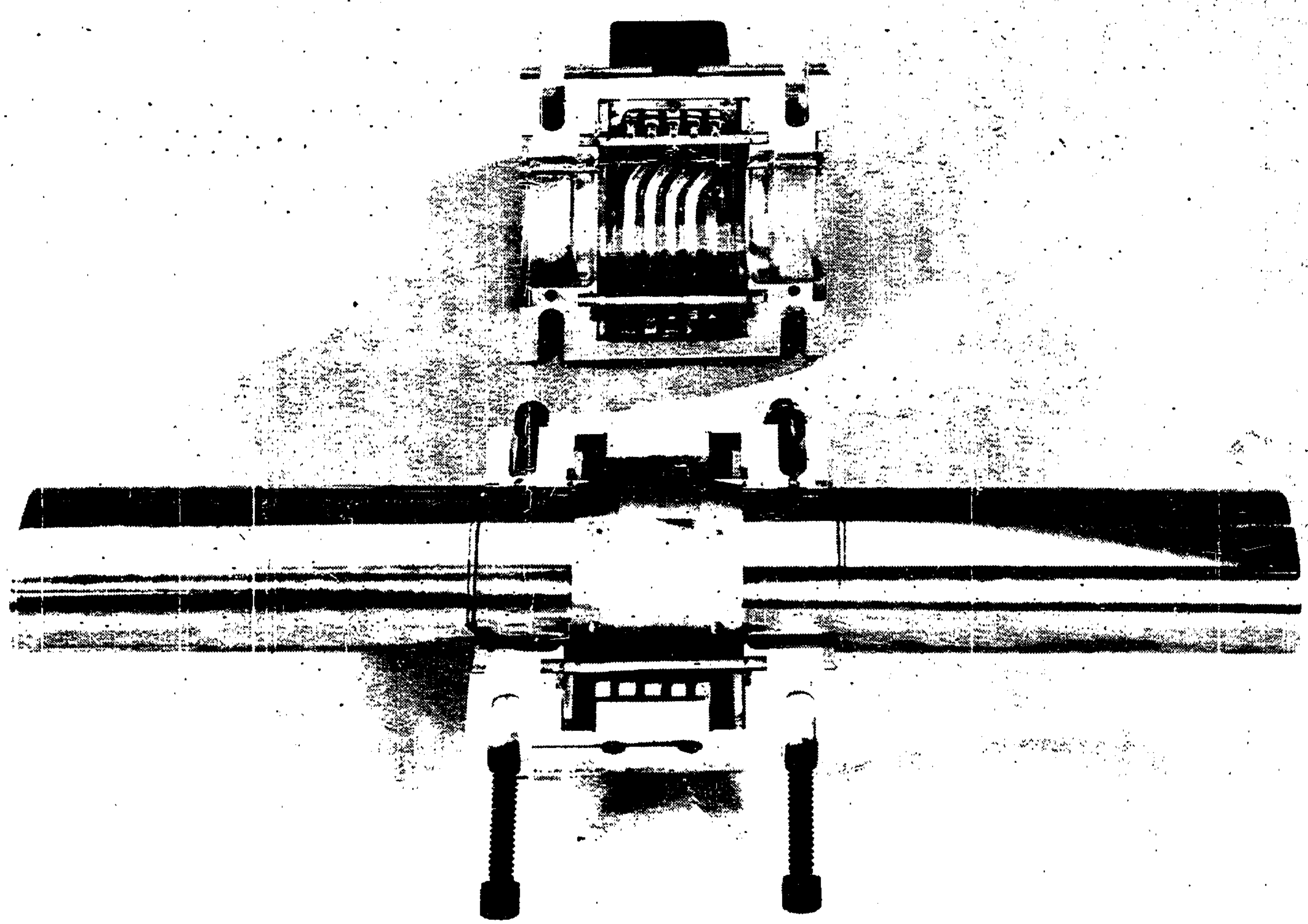


Figure 60. Split-Type Reusable Coil Induction Brazing Tool

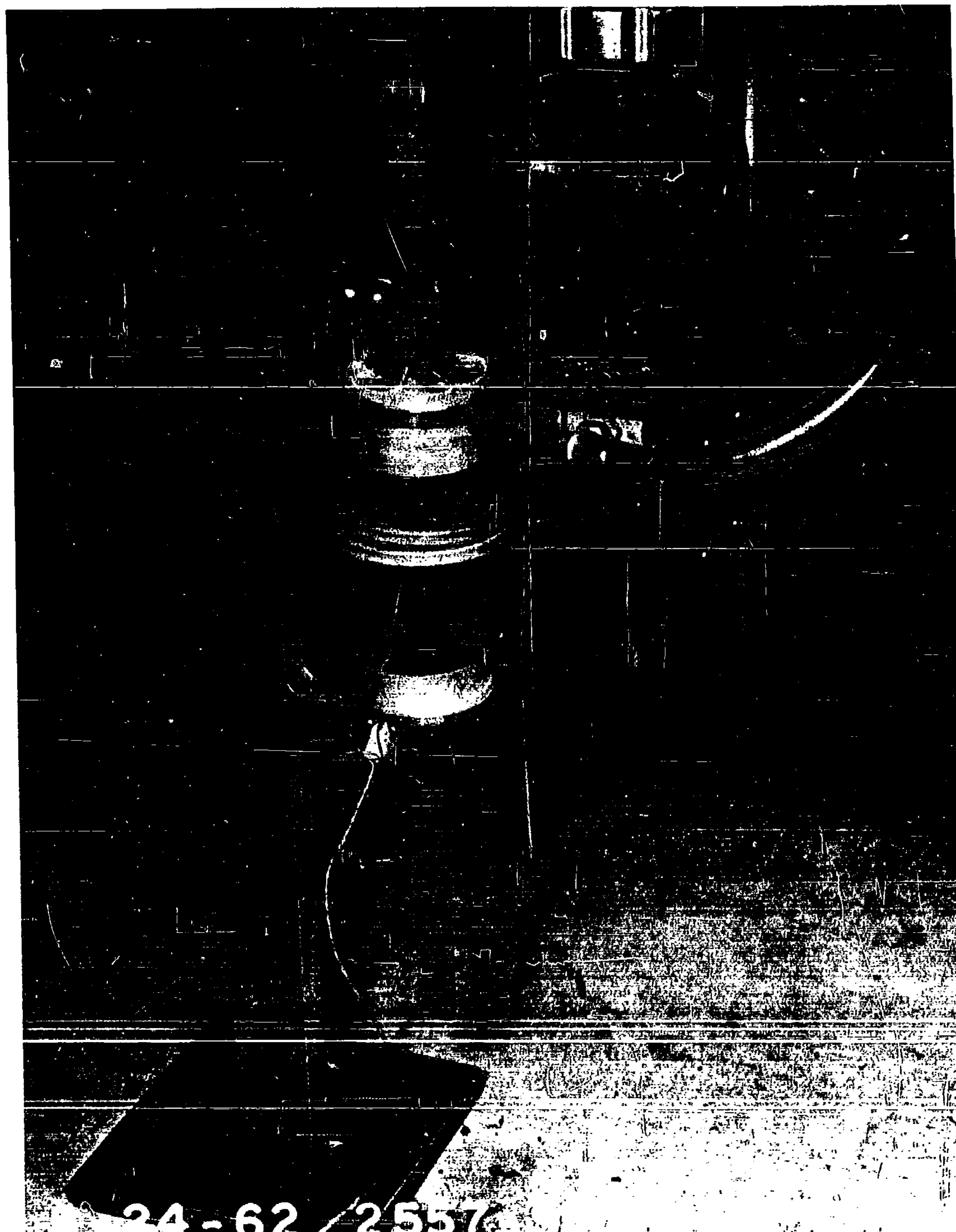


Figure 61. Apparatus for Rebrazing Feasibility Preliminary Tests

The Rene' 41 butt joint made with the 82Au-18Ni alloy was debrazed and rebrazed a total of five times. These operations were conducted at temperatures both above and also somewhat below the nominal 1742 F melting temperature of this brazing alloy. It was possible to pull the joint apart at temperatures of the order of 1600 F to 1650 F, and then cause the alloy to rebond at temperatures of 1650 F to 1700 F. This was done in an argon atmosphere. The debonding and rebonding below the melting temperature of the brazing alloy can be accomplished because of the particular nature of gold alloys as regards their known malleability and dry welding or pressure bonding characteristics, Reference (20). The joints were examined after each braze operation and were found to be of sound quality with no apparent voids or discontinuities.

The joint made with the 60Pd-40Ni-0.3Li alloy was brazed and debrazed twice and then rebrazed a third time. Examination of this joint showed a poor quality braze after the third braze operation. It appeared that the lithium in this brazing alloy had dissipated during the first two brazing and debrazing operations. Since the lithium in this alloy served as a volatile flux and also improved wettability and flow characteristics, when it was gone the brazing alloy was no longer capable of proper wetting and flow to reform a sound joint. In this connection, it can be expected that the silver-base brazing alloys which contain lithium as a fluxing agent will react in a similar manner. That is, they will be capable of only a very limited number of debrazing and rebrazing operations because of lithium volatilization and depletion from the alloy.

An attempt was made to debraze and rebraze the nickel plated and brazed Rene' 41 tube joint shown in Figure 53, page 113. This joint was made with the 82Au-18Ni brazing alloy. The joint was successfully debrazed in an argon atmosphere. Examination of the debrazed joint showed good adhesion of the brazing alloy to the base metal, and full flow and wetting of the joint capillary surfaces. The rebrazing operation was not successful. During attempts to prepare the joint for rebrazing some of the brazing alloy was inadvertently removed from the joint surfaces. Then, during the rebrazing operation when the tube end was moved into the fitting at brazing temperature, air leaked into the plenum chamber through a defective end seal. This contaminated the argon atmosphere and caused the formation of oxide on the Rene' 41 surfaces and within the joint which prevented the braze alloy from proper flow and wetting of the joint surfaces.

Repair of brazed joints can be successfully accomplished by a number of different methods, Reference (82). A repair can be made by complete removal of the defective joint by cutting the tubing on both sides of the joint, and then replacing the cutout section by brazing a new length of tubing in place using two new fitting sleeves with the new brazed joints. A second method to replace a cutout defective joint is to use a specially designed fitting sleeve which is long enough to bridge the cutout section.

The above systems have been used successfully, but they add weight to the tubing system. Where weight considerations are important it may be preferable to reheat and debraze not only the defective joint, but also the nearest joint to the defective one. Then, two fitting sleeves and the

length of tubing between the two joints can be removed. The tubing is cleaned, using the procedure described in paragraph 5.3, page 115of this Section, and two new fitting sleeves with new brazing alloy are used to rebraze the length of tubing back into place. The use of new fitting sleeves is recommended because of the problems which are encountered in cleaning the used sleeves. The old brazing alloy must be removed by acid etching which is a time consuming process and can cause damage to the fitting sleeve material. After cleaning the fitting sleeves may be found to be unusable because of distortion caused by the previous braze cycle.

Debrazing and rebrazing should be used only where absolutely necessary because it involves extra costs in time and materials. New braze alloy should always be used, even when the old sleeves are reused because of mechanical loss of the original alloy in the reheating cycles and during the cleaning operation. Other reasons why debrazing and rebrazing of a joint using the original components is not desirable are: (1) repeated heatings expose the joint components to more opportunities for contamination and oxidation, (2) the lithium or other fluxing agent in the original braze alloy is depleted by volatilization or reaction with the surface oxides on the joint components and therefore its fluxing and wetting effect in the brazing operation is lost, (3) there is a gradual diffusion of the braze alloy into the base metal which changes the composition and properties of both the remaining braze alloy and also the joint component materials, and (4) extended times at brazing temperatures can produce damaging metallurgical changes such as carbide precipitation in the AISI type 347 stainless steel or overaging and loss of strength in precipiation hardening materials such as AM 350 and Rene' 41, References (26) and (47).

6. QUALIFICATION TEST PROGRAM

6.0 GENERAL

The objective of the Qualification Test Program was to demonstrate the capability of the fitting assemblies to meet in a satisfactory manner the specified performance and environmental requirements. The tests which were performed during this program and the environmental conditions under which they were performed are presented in Table XVII. The relationship between the various qualification tests and the sequence for the fitting assemblies of a given family of fittings are shown in Figure 62.

6.1 SUMMARY OF RESULTS

A total of 76 tube and tube joint specimens were tested for leakage, proof pressure, burst pressure, vibration, etc., during the specimen development and the qualification testing programs. Seven parent tube specimens and seven joint assembly specimens were tested during the course of the development of joint and fitting sleeve configurations. Sixty-two specimens were used in the qualification test program. Testing was completed for 54 of the qualification test specimens. Of these, 21 were brazed joint specimens and 33 were welded joint specimens. In addition, three brazed joint specimens and five welded joint specimens were damaged during testing. The results of the qualification tests are presented in Table XVIII and Appendix I, page 168.

Each of the types of joints which were submitted for qualification testing successfully passed the proof pressure, leakage, burst pressure, temperature shock, and pressure impulse requirements. The AISI type 347 stainless steel welded joint specimens also passed the vibration and stress reversal bending test requirements. The AM 350 stainless steel brazed joint and welded joint specimens passed the vibration test requirements but did not complete the required life of 200,000 cycles for each of the stress reversal bending tests. The AISI type 347 stainless steel brazed joint specimens and the 6061 aluminum alloy welded joint specimens did not complete the life of 2,000,000 cycles which had been established in the Detail Test Plan as a target requirement for the vibration tests Reference (83), nor did they complete the life of 200,000 cycles required for each of the stress reversal bending tests. The Rene' 41 alloy 1/8 inch diameter brazed joint and welded joint specimens did not complete the stress reversal bending tests; however, these particular specimens appeared to have been damaged sometime during the course of the testing.

The failures in the above specimens were in the form of fatigue cracks which developed in the tubing at the edge of the fitting sleeve or, in the cases of the specimens with simple fusion butt weld joints, in the heat affected zone adjacent to the joint weld bead. The requirements of the vibration and stress reversal bending tests were that the specimen test joints be repeatedly stressed at a bending stress equivalent to 75 percent of the yield strength of the specimen tubing material. Fatigue information

TABLE LVII. PERFORMANCE AND ENVIRONMENTAL CONDITIONS FOR QUALIFICATION TESTING.

SERVICE	MATERIAL	SYSTEM OPERATING PRESSURE (psig)	TEST SPECIMEN TUBE SIZE (in.) OD	WALL THICKNESS	QUALIFICATION TEST DESCRIPTION	ONE SPECIMEN OF EACH TYPE JOINT AS NOTED WAS TESTED FOR EACH INDICATED TEST -320F	ROOM	200F	600F	1500F
Propellant	Type 347 Stainless Steel	0 to 2500	1	.083	Burst			x		
					Stress Rev. Bend	x		x		
					Vibration			x		
					Temp. Shock	-		x		
					Pressure Impulse	x		x		
			3	.250	Burst			w		
					Stress Rev. Bend	w		w		
Pneumatic	6061-T6 Aluminum Alloy	0 to 1000	1	.058	Burst			w		
					Stress Rev. Bend	w		w		
					Vibration			w		
					Temp. Shock	-		w		
					Pressure Impulse	w		w		
	AM 350 CRT Stainless Steel	0 to 10,000	1/4	.042	Burst				x	
					Stress Rev. Bend	x			x	
	AM 350 SCT Stainless Steel	0 to 10,000	1	.134	Burst				x	
					Stress Rev. Bend	x			x	
					Vibration				x	
					Temp. Shock	-			x	
					Pressure Impulse	x			x	
	Rene' 41 Alloy	0 to 4000	1/8	.010	Burst					x
					Stress Rev. Bend	x	x			x

Note: "x" indicates both welded and brazed joint specimens were tested.
"w" indicates only welded joint specimens were tested.

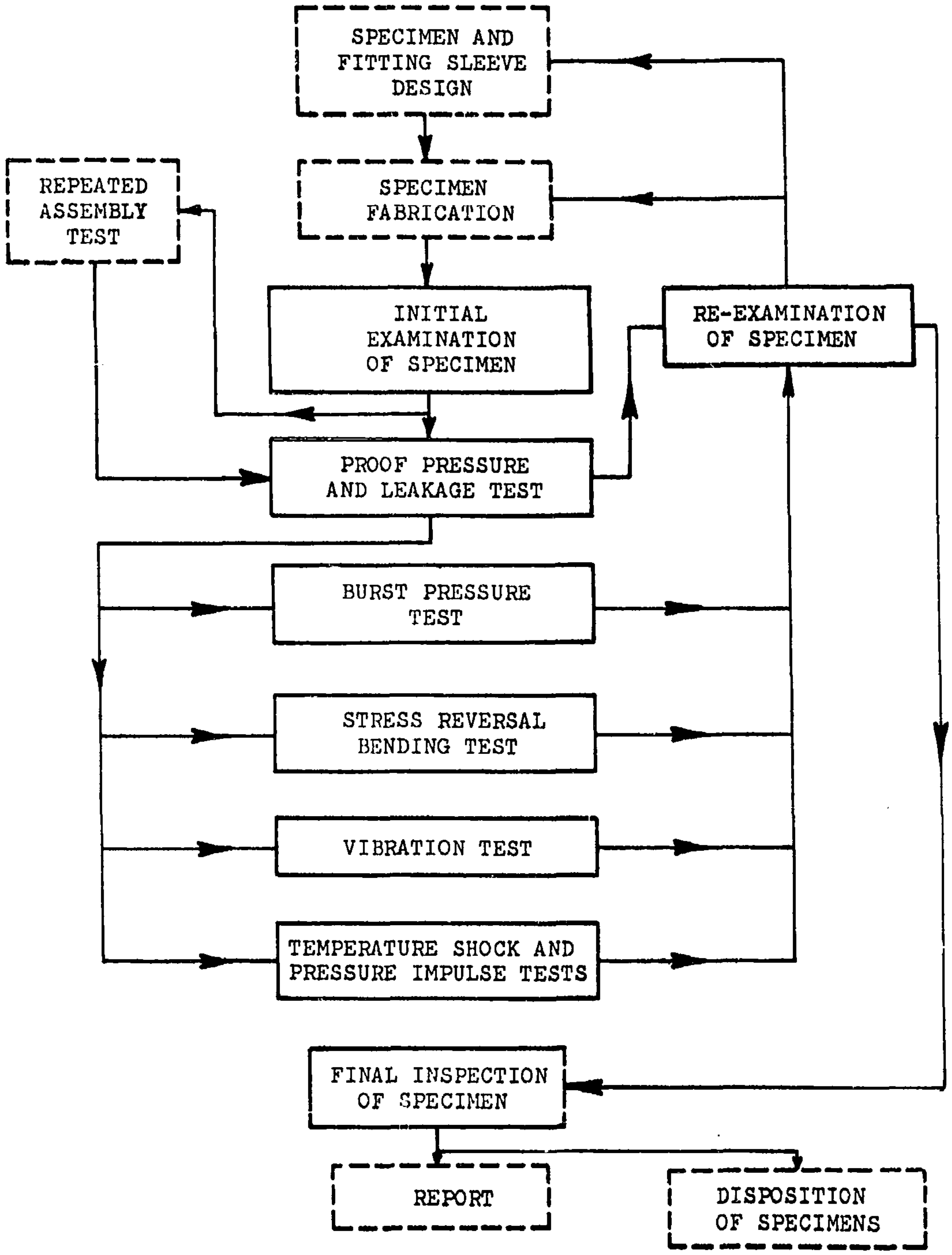


FIGURE 62. FLOW CHART SHOWING SEQUENCE OF QUALIFICATION TESTS FOR A FAMILY OF SPECIMENS.

TABLE XVIII. SUMMARY OF RESULTS OF QUALIFICATION TESTS.

SPECIMEN TUBING MATERIAL	MAXIMUM SYSTEM OPERATING PRESSURE	SPECIMEN TUBE SIZE (inches)		TYPE OF JOINT	PROOF PRESSURE AND LEAKAGE TESTS			BURST TESTS AND TEST TEMPERATURE	STRESS REVERSAL BENDING TESTS			T S T
		OD	WALL		-320F	Room Temp.	Elev. Temp.		-320F	Room Temp.	Elev. Temp.	
Type 347 Stainless Steel	2500 psi	1	.083	Brazed Welded	P P	- -	P P	P at 200F P at 200F	P P	- -	F (a) P	
		3	.250	Welded	P	-	P	P at 200F	P	-	P	
AM 350 Stainless Steel	10,000 psi	1/4	.042	Brazed Welded	P P	- -	P P	P at 600F P at 600F	P P	- -	F (c) (d)(e)	
		1	.134	Brazed Welded	P P	- -	P P	P at 600F P at 600F	(f) P	- -	F (g) F (h)	
Rene' 41 Alloy	4000 psi	1/8	.010	Brazed Welded	P P	P P	P P	P at 1500F P at 1500F	(e)(i) (e)(l)	(e)(j) (m)	(e)(k) (e)(m)	
6060 Aluminum Alloy	1000 psi	1	.058	Welded	P	-	P	P at 200F	P	-	F (o)	

NOTES:
(a) Leakage occurred after 71,500 cycles at 19,500 psi maximum bending stress; crack in t of fitting sleeve.
(b) Leakage occurred after 269,000 cycles at dynamic mid-span bending stress of 19,500 ps at edge of fitting sleeve.
(c) Leakage occurred after 156,500 cycles at 32,600 psi maximum bending stress; crack in of fitting sleeve.
(d) Leakage occurred after 91,800 cycles at 32,600 psi maximum bending stress; crack deve
(e) Specimen appeared to have been accidentally damaged during testing.
(f) Fracture of tubing at bending edge of fitting sleeve after 70,100 cycles at 59,700 ps
(g) Leakage occurred after 80,000 cycles at 34,000 psi maximum bending stress; crack in t of fitting sleeve.
(h) Circumferential crack at junction of weld and tube occurred between 94,400 and 183,00 maximum bending stress at 600 F.
(i) Leakage occurred after 25,000 cycles at 86,250 psi maximum bending stress; crack in t of fitting sleeve.
(j) Leakage occurred after 58,500 cycles at 67,100 psi maximum bending stress; crack in t of fitting sleeve.
(k) Brazed joint did not fail. Parent tubing cracked at edge of fixed support grip after maximum bending stress. During initial set-up at room temperature this part was acci psi maximum bending stress.
(l) Welded joint did not fail. Parent tubing cracked at edge of fixed support grip after maximum bending stress.
(m) Specimen was damaged when part of test fixture broke after 19,750 cycles at 62,700 ps
(n) Fracture of tubing at fixed support grip edge of fitting sleeve after 125,700 cycles bending stress at 1500 F.
(o) Circumferential crack at junction of weld and tube adjacent to strain gage occurred a psi maximum bending stress at 200 F.
(p) Failure occurred after 137,500 cycles at dynamic mid-span bending stress of 12,000 ps

TABLE XVIII. SUMMARY OF RESULTS OF QUALIFICATION TESTS.

AXIMUM YSTEM ERATING ESSURE	SPECIMEN TUBE SIZE (inches) OD	WALL	TYPE OF JOINT	PROOF PRESSURE AND LEAKAGE TESTS -320F	Room Temp.	Elev. Temp.	BURST TESTS AND TEST TEMPERATURE	STRESS REVERSAL BENDING TESTS -320F	Room Temp.	Elev. Temp.	TEMP. SHOCK TESTS	PRESSURE IMPULSE TESTS -320F	Elev. Temp.	VIBRATION TESTS
500 psi	1	.083	Brazed Welded	P P	- -	P P	P at 200F P at 200F	P P	- -	F (a) P	P P	P P	P P	F (b) P
	3	.250	Welded	P	-	P	P at 200F	P	-	P	-	-	-	-
,000 psi	1/4	.042	Brazed Welded	P P	- -	P P	P at 600F P at 600F	P P	- -	F (c) (d)(e)	- -	- -	- -	- --
	1	.134	Brazed Welded	P P	- -	P P	P at 600F P at 600F	(f) P	- -	F (g) F (h)	P P	P P	P P	P P
000 psi	1/8	.010	Brazed Welded	P P	P P	P P	P at 1500F P at 1500F	(e)(i) (e)(l)	(e)(j) (m)	(e)(k) (e)(m)	- -	- -	- -	- -
000 psi	1	.058	Welded	P	-	P	P at 200F	P	-	F (o)	P	P	P	F (p)

Leakage occurred after 71,500 cycles at 19,500 psi maximum bending stress; crack in tubing at fixed support edge of fitting sleeve.
Leakage occurred after 269,000 cycles at dynamic mid-span bending stress of 19,500 psi at 200F; crack in tubing at edge of fitting sleeve.
Leakage occurred after 156,500 cycles at 32,600 psi maximum bending stress; crack in tubing at fixed support edge of fitting sleeve.
Leakage occurred after 91,800 cycles at 32,600 psi maximum bending stress; crack developed in test weld joint.
Specimen appeared to have been accidentally damaged during testing.
Fracture of tubing at bending edge of fitting sleeve after 70,100 cycles at 59,700 psi maximum bending stress.
Leakage occurred after 80,000 cycles at 34,000 psi maximum bending stress; crack in tubing at fixed support edge of fitting sleeve.
Circumferential crack at junction of weld and tube occurred between 94,400 and 183,000 cycles at 34,600 psi maximum bending stress at 600 F.
Leakage occurred after 25,000 cycles at 86,250 psi maximum bending stress; crack in tube at fixed support edge of fitting sleeve.
Leakage occurred after 58,500 cycles at 67,100 psi maximum bending stress; crack in tube at fixed support edge of fitting sleeve.
Brazed joint did not fail. Parent tubing cracked at edge of fixed support grip after 23,200 cycles at 56,000 psi maximum bending stress. During initial set-up at room temperature this part was accidentally stressed to 84,700 psi maximum bending stress.
Welded joint did not fail. Parent tubing cracked at edge of fixed support grip after 16,150 cycles at 88,500 psi maximum bending stress.
Specimen was damaged when part of test fixture broke after 19,750 cycles at 62,700 psi maximum bending stress.
Fracture of tubing at fixed support grip edge of fitting sleeve after 125,700 cycles at 54,500 psi maximum bending stress at 1500 F.
Circumferential crack at junction of weld and tube adjacent to strain gage occurred after 27,000 cycles at 11,900 psi maximum bending stress at 200 F.
Failure occurred after 137,500 cycles at dynamic mid-span bending stress of 12,000 psi at 200F; crack at weld.

for the test materials shows that, at this level of stress, the various tube joint specimens actually attained quite reasonable lives before failure, References (69) to (71) and (84). There were no failures of either the fitting sleeves or in the joint weld bead itself. All failures occurred in the specimen tubing. Therefore, even though these particular test specimens may not have completed the lives desired for the vibration or the stress reversal bending tests, the joints in the specimens were considered to be acceptable for reasonable usage in rocket propulsion fluid systems.

6.2 TEST FLUIDS

The following fluid media were used during the Qualification Testing Program.

(1) Gaseous helium
(2) Gaseous nitrogen
(3) Liquid nitrogen
(4) Compressed air
(5) Oronite 8200 Disiloxane Base Hydraulic Fluid, NAA Specification No. LB0145-100

The liquid nitrogen was used to provide the -320 F temperature for those tests requiring that low temperature environment. Gaseous helium was used as the pressurizing medium for all proof pressure and leakage tests and for the -320 F and 1500 F burst pressure tests. Gaseous nitrogen was used as the pressurizing medium for the -320 F and 1500 F pressure impulse and stress reversal bending tests. The Oronite 8200 fluid was used as the pressurizing medium for the 200 F and 600 F pressure impulse and burst pressure tests. Compressed air was used for failure detection in the vibration tests and for locating the test failures in the specimens from the various tests.

6.3 TESTING SYSTEMS

System Schematics

The schematic diagrams for the 15,000 psig fluid pressurization systems used for the -320 F and 600 F pressure impulse tests are shown in Figures 63 and 64, respectively. These systems incorporated a Hydraulic Pressure Booster and a Gas Intensifier Accumulator, both of which are described below.

The schematic diagrams for the pressurization systems used for fluid pressures up to 6000 psig for the -320 F and 600 F pressure impulse tests are shown in Figures 65 and 66, respectively. These systems achieved the testing pressures by use of a 5000 psig pressure hydraulic fluid supply pump and pressurized bottled gas in conjunction with the Gas Intensifier Accumulator.

Pressurization Equipment

The following equipment and procedures were used to produce the internal pressures in the test specimens.

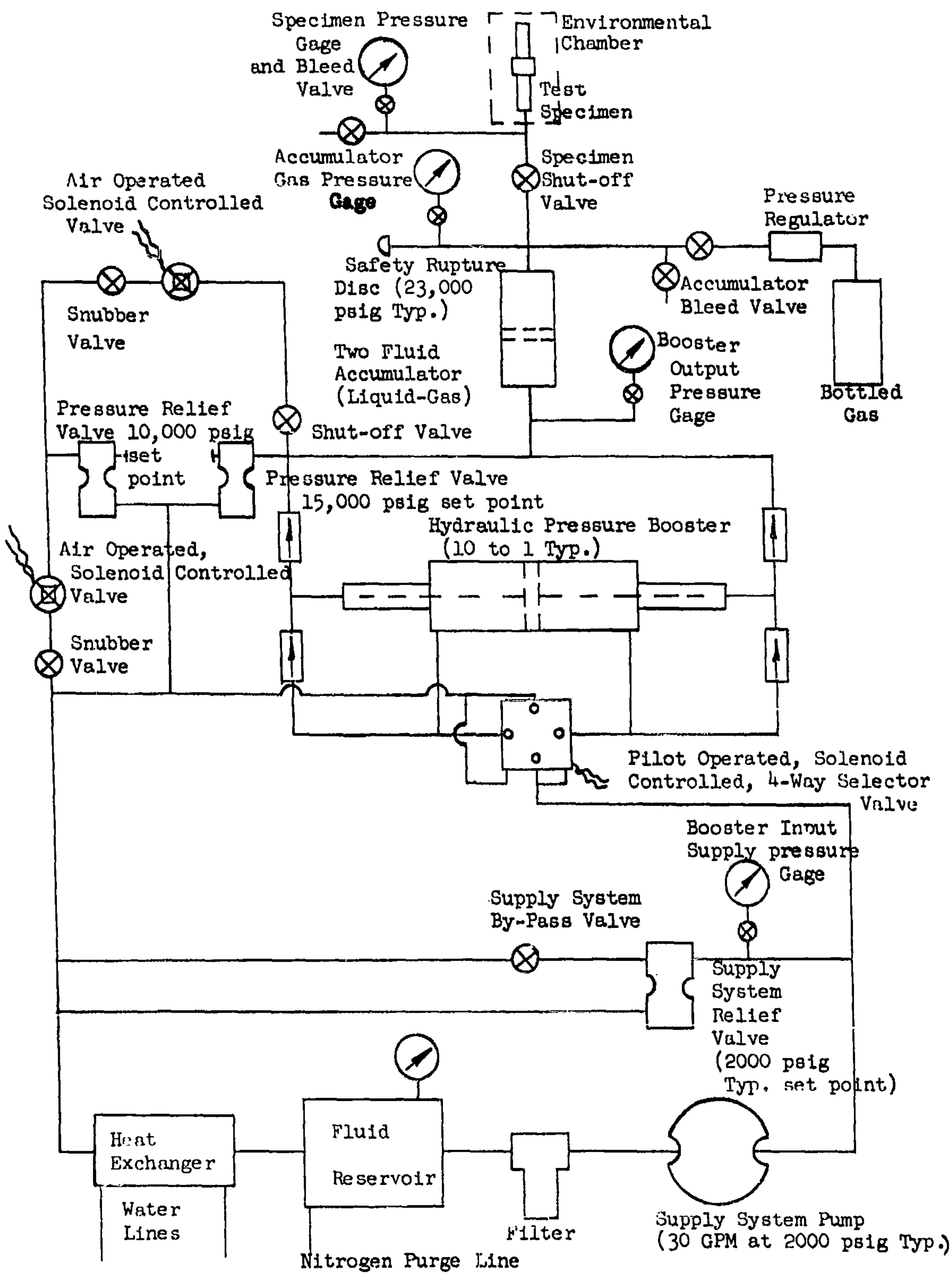


Figure 63. Schematic Diagram for 0 to 15,000 psig Pressure Cycling Tests at -320 F.

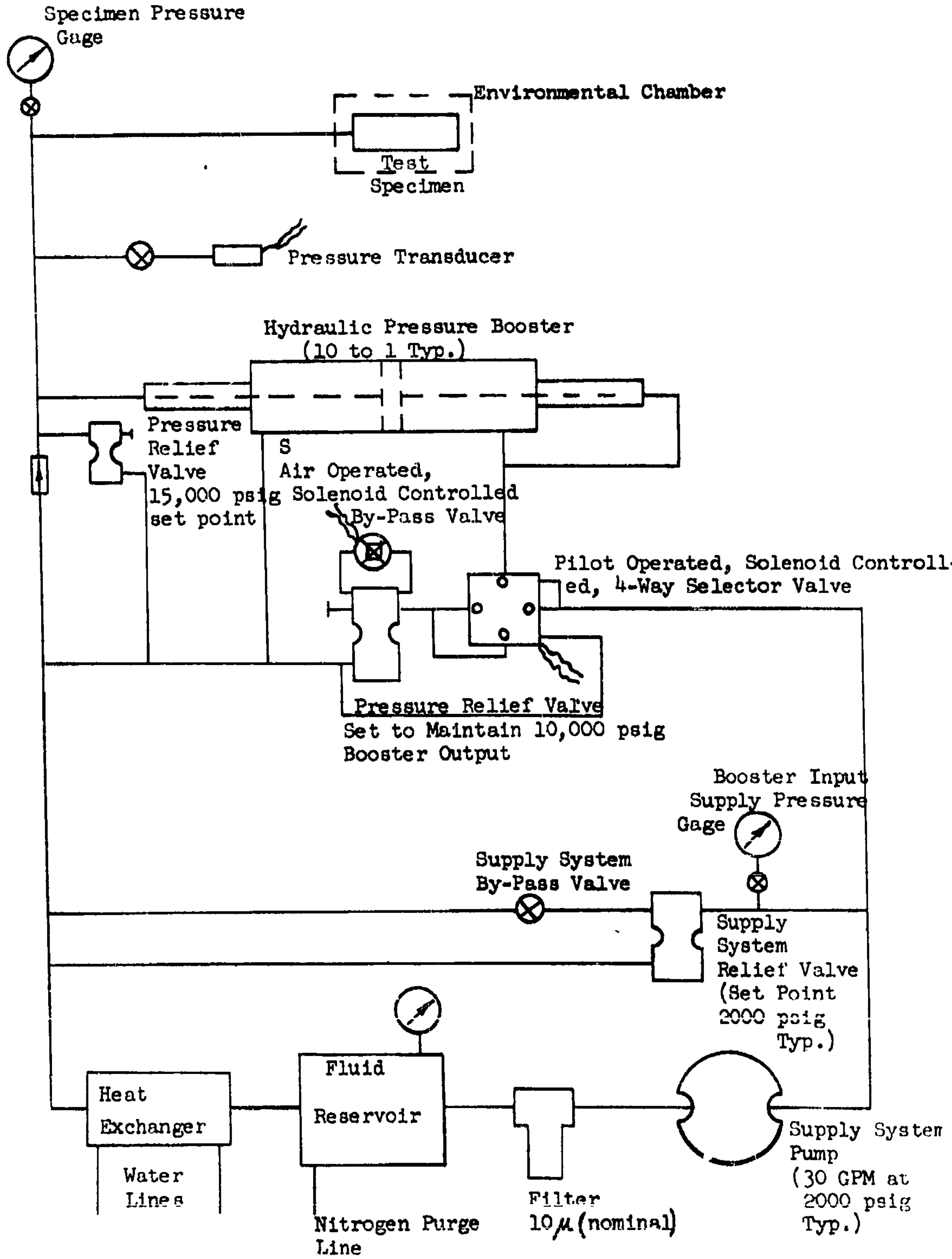


Figure 64. Schematic Diagram for 0 to 15,000 psig Pressure Cycling Tests at 600 F.

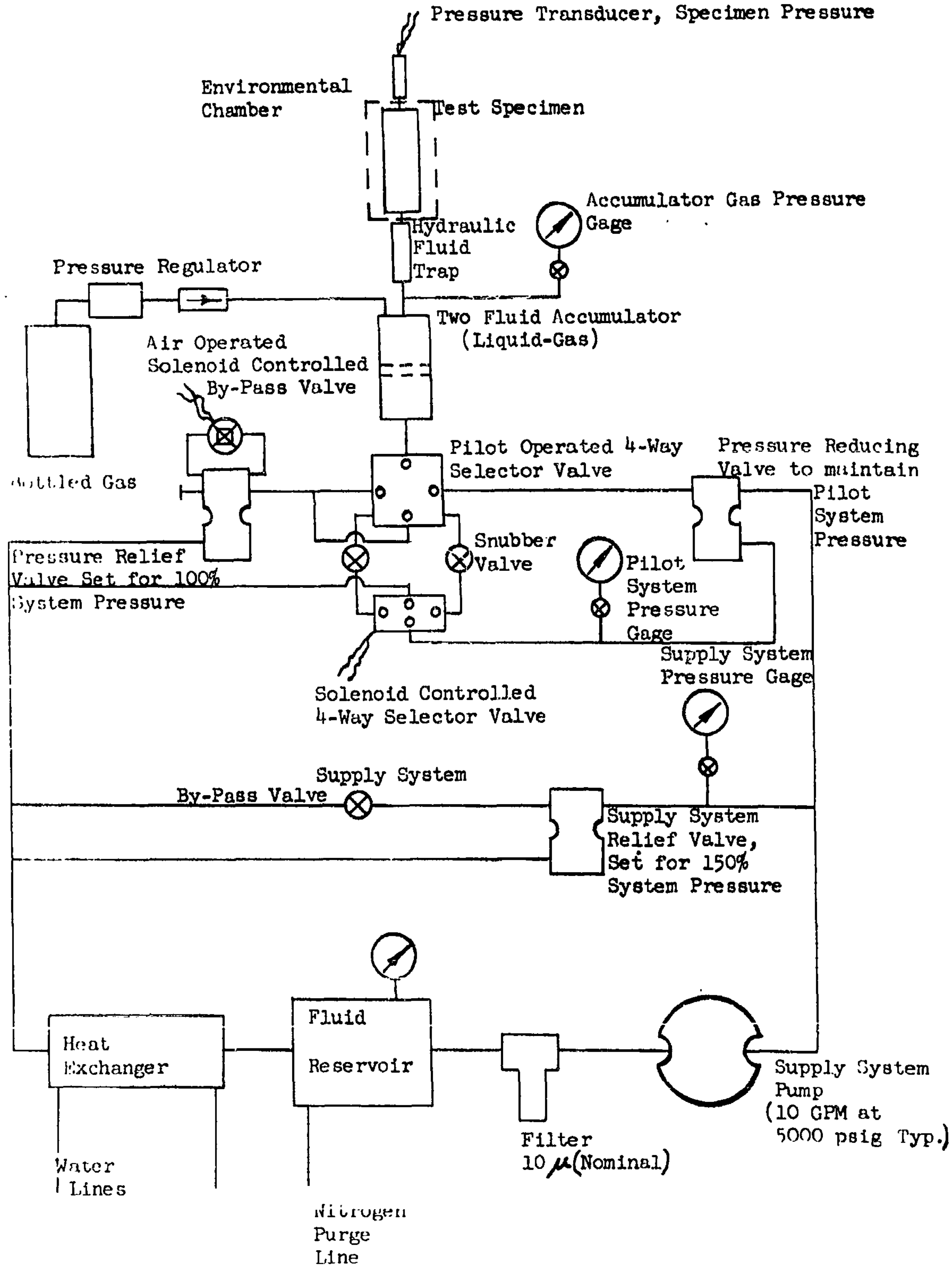


Figure 65. Schematic Diagram for 0 to 6000 psig (Inclusive) Pressure Cycling Tests at -320 F.

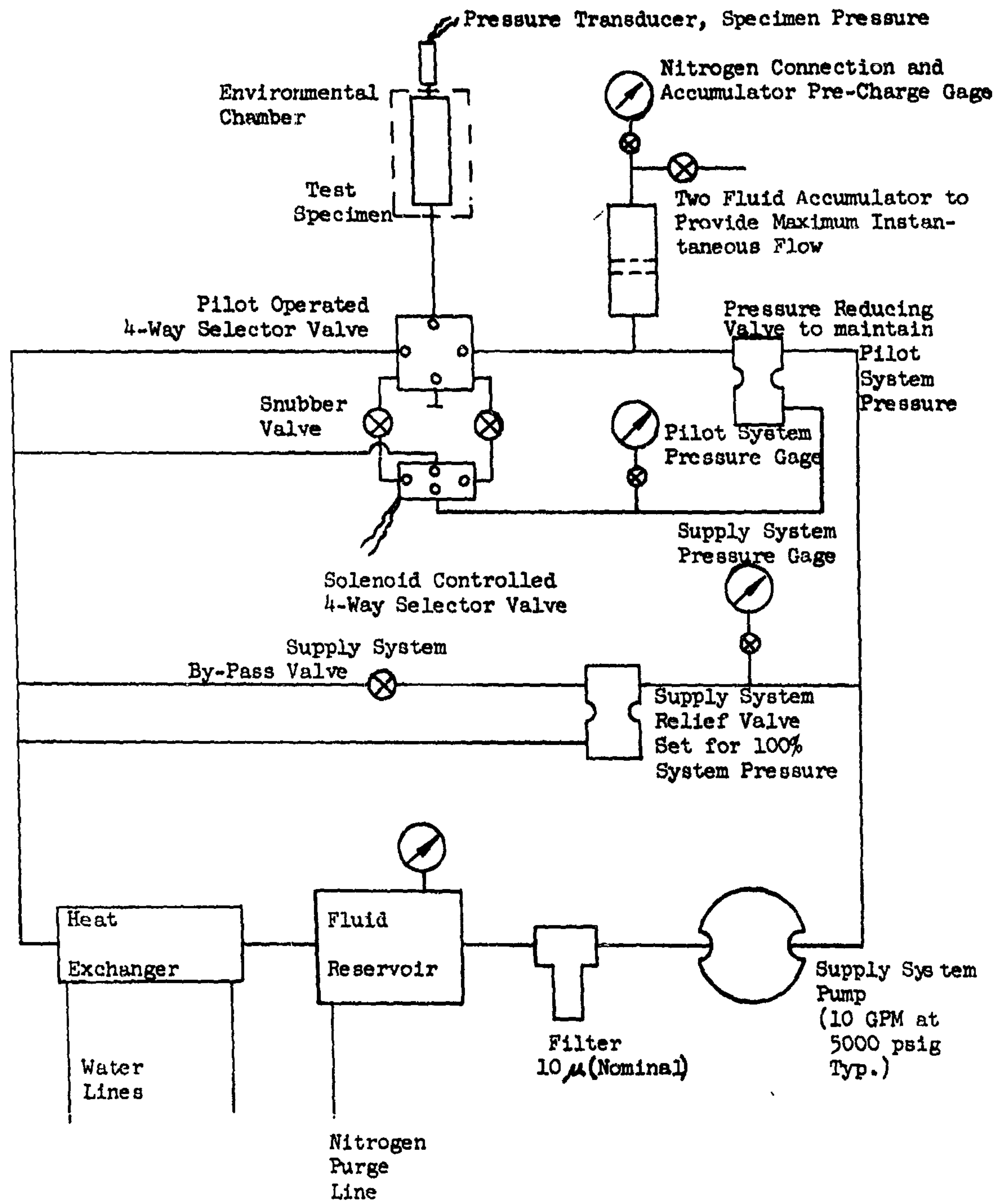


Figure 66. Schematic Diagram for 0 to 6000 psig (Inclusive) Pressure Impulse Cycling Tests to 600 F.

A liquid intensifier system was used to pressurize the liquid fluid test medium to the required very high system pressures. A Hydraulic Pressure Booster made by the Miller Fluid Power Division, Flick-Reedy Corporation, Bensenville, Illinois, was designed and built to NAA specifications. This equipment was used to boost 2000 psig hydraulic fluid pressure to 20,000 psig hydraulic fluid pressure for the burst test requirement. The Booster also was able to supply up to four gpm liquid flow (with a 30 gpm input) for the proof pressure and leakage test requirements.

The Hydraulic Pressure Booster operated in the following manner. The 2000 psig pressure was supplied by conventional pumps. The flow of liquid to the chambers of the Booster was controlled by a directional control valve. The difference in area of the input piston and the output plunger produced a pressure boost of approximately 10 to 1. The system was set up with check valves arranged to maintain almost continuous flow from the double-acting Booster. The Gas Intensifier Accumulator served to reduce the pressure fluctuations during the Hydraulic Pressure Booster piston reversal.

A two-fluid Accumulator was used in the Gas Intensifier system. The Accumulator was designed and built by Autoclave Engineers, Inc., to NAA specifications. This Accumulator was used to store helium or nitrogen gas and to serve as a barrier between the high pressure liquid and the gas when the high pressure liquid discharged from the Hydraulic Pressure Booster is being used to pressurized the gas. Prepressurized gas was used when the flow rate or volume required. This system was used for the proof pressure and leakage tests. Burst pressure tests were performed utilizing gas as the pressurizing medium only when the extreme temperatures encountered during certain tests precluded the use of liquids as the pressurizing medium.

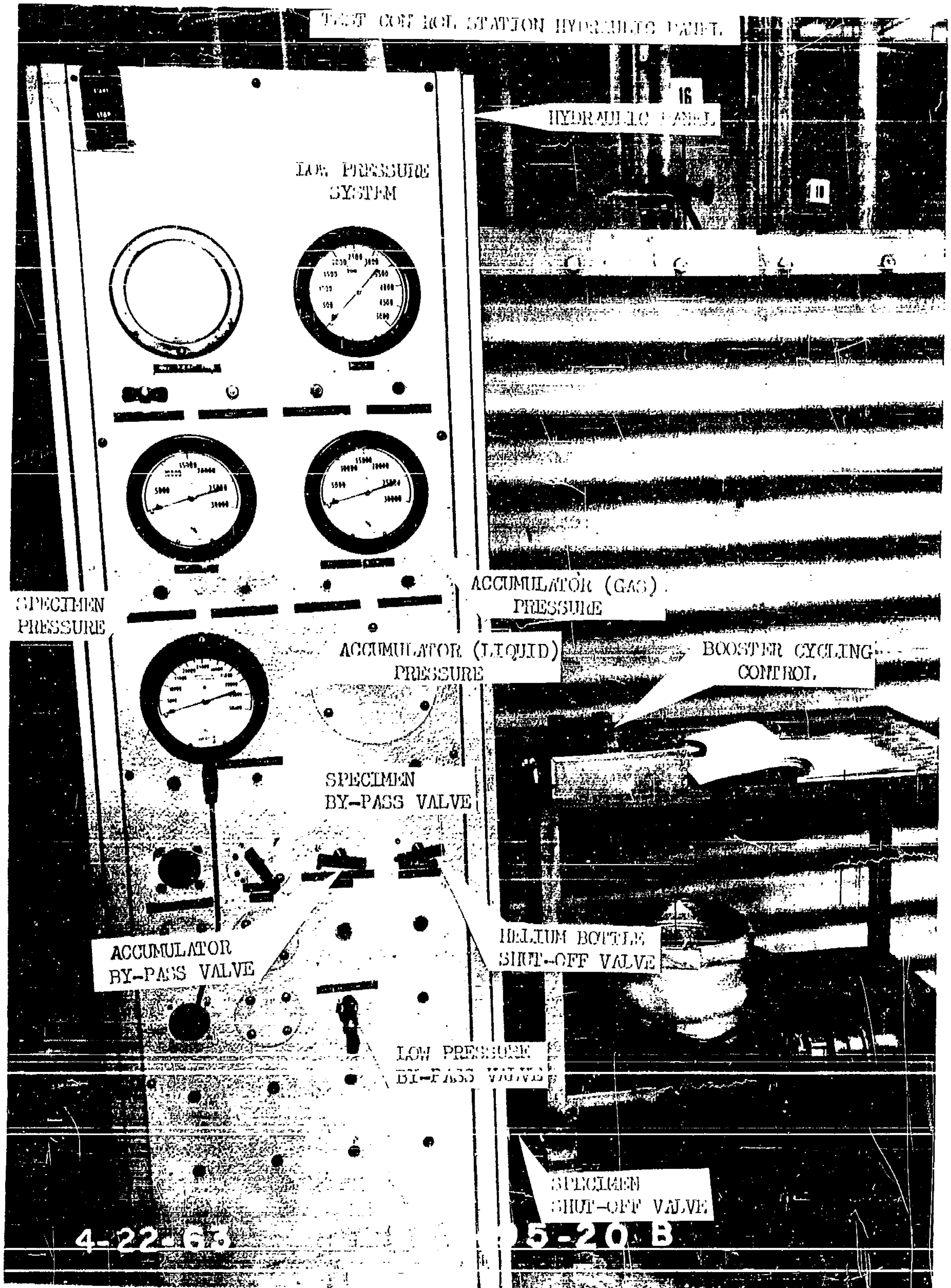
Pressure impulsing was accomplished in the following manner. Removal of the Accumulator from the liquid pressure system and slight opening of the pressure by-pass valve produced a square wave form of pressure impulse sufficient to meet the impulse test pressure requirements. The Hydraulic Pressure Booster was cycled by means of a timer. The basic equipment set-up is shown in Figures 67 and 68.

Environmental Temperature Equipment

The following Equipment was used to attain the temperatures required for the test conditions shown in Table XVII, page 135.

Hevi-Duty Electric Co. exposed element radiation type heaters of the semi-cylindrical type were used to produce the 1500 F test temperatures. Thermocouples on the test specimen were used to measure the test temperatures and for heater control.

An environmental chamber with air circulation convection heat, thermocouple controlled, was used for the 200 F and 600 F tests.


TEST CONTROL STATION HYDRAULIC PANEL
HYDRAULIC PANEL
LOW PRESSURE SYSTEM
SPECIMEN PRESSURE
ACCUMULATOR (GAS) PRESSURE
ACCUMULATOR (LIQUID) PRESSURE
BOOSTER CYCLING CONTROL
SPECIMEN BY-PASS VALVE
ACCUMULATOR BY-PASS VALVE
HELIUM BOTTLE SHUT-OFF VALVE
LOW PRESSURE BY-PASS VALVE
SPECIMEN SHUT-OFF VALVE
4-22-63
5-20 B


PRESSURE SYSTEM USED FOR LEAK,
PROOF PRESSURE, AND BURST PRESSURE TESTING
LOW PRESSURE
SYSTEM
BOOSTER
SPECIMEN
SHUT-OFF
ACCUMULATOR
4-22-63 2557-95-20C

The -320 F temperature for the stress reversal bending tests was attained by immersing the test specimen in a container of liquid nitrogen. A thermocouple on the test specimen was used to verify the test temperature.

For the pressure impulse testing at -320 F, the test specimen was immersed in a container of liquid nitrogen. Thermocouple control of the temperature of the pressurizing fluid was used to insure that the pressurizing fluid flow was sufficient to prevent the fluid from freezing. The test specimen temperature also was checked by means of thermocouples.

For the -320 F to 1500 F thermal shock tests, the specimen was to have been alternately subjected to a flame from propane burners and to a stream of liquid nitrogen from appropriately arranged spray nozzles. The test specimen temperature was to be determined by means of the thermocouples. The equipment for these tests was set up and checked out, but the tests were not conducted because the one-inch diameter Rene' 41 alloy tubing for the test specimens was found to be defective and was rejected. Further work on this material was suspended under this contract by order of the USAF Project Engineer, but it is planned that this work will be accomplished as part of a future USAF program.

The thermal shock tests at -320 F to 200 F, and also at -320 F to 600 F, utilized a hot air blast impinging of the test specimen alternating with a liquid nitrogen stream. Thermocouples were used to determine the test specimen temperatures.

6.4 TEST PROCEDURES

General

The flow chart shown in Figure 62, page 136 presents the relationship between the several qualification tests and the sequence in which the fitting assemblies were subjected to the tests. Each type of test is described in the following paragraphs.

Initial Examination of Specimens

All test specimens were inspected before testing to determine conformance with the applicable drawings and specifications. The examination was especially directed toward detecting possible defects in assembly or workmanship. Where required, the test specimens were also examined for defects after one or more of the qualification tests had been performed. This examination was used to assess the amount of damage, if any, incurred by the specimen during test; and the results of this examination were compared with the findings of the initial examination.

Proof Pressure and Leakage

Proof pressure for the joint assemblies to be tested is specified as 150 percent of the maximum system operating pressure. The joint assembly was required to withstand this internal pressure for five (5) minutes

with no leakage or permanent distortion resulting. All test specimens were subjected to this test prior to other qualification testing. Testing was performed at the pressures and temperatures shown in Table XVII. Leakage was determined at the maximum design operating temperature, and also at -320 F.

Gaseous helium was used as the pressurizing fluid medium. A Beckman Leak Detector, Model No. 140, was connected to a leak trap fitted around the test joint to detect any leakage. The leak detection operating sensitivity was about 2×10^{-9} atmcc/sec of helium. However, the leak traps did not always fit tightly around the specimen joint. Therefore, the operating sensitivity of the leak detection set-up was approximately only 6×10^{-8} atmcc/sec of helium for some of the tests. This set-up is shown in Figure 69.

Burst Pressure

Burst pressure for the joint assemblies to be tested is specified as 200 percent of the maximum system operating pressure. The joint assembly was required to withstand this internal pressure for a period of five (5) minutes at the maximum design operating temperature with no joint rupture resulting. Burst tests were performed at the pressures and temperatures shown in Table XVIII, page 137. A typical burst pressure test set-up is shown in Figure 70.

Stress Reversal Bending

The stress reversal bending specimens were tested as cantilever beams with the test joint located at the fixed end of the specimen, as shown in the sketches of Figures 71 and 72. The test consisted of repeatedly deflecting the specimens so as to impose at the test joint completely reversed bending stresses ($R = -1.0$) equivalent to 75 percent, maximum, of the yield strength of the specimen tubing material at the testing temperature. The required life of the test joints was specified as 200,000 cycles, or the life of the specimen tubing material if it failed first. Stress reversal bending tests were conducted under the environmental conditions shown in Table XVIII, page 137.

The specimens for the stress reversal bending tests were installed in the test fixture in a straight or neutral position, as shown in Figure 73. The specimens were then deflected first to one side of the neutral position and then to the other side by means of an eccentric type drive mechanism which imparted a predetermined deflection to the free end of the cantilever beam test specimen. The nominal specimen deflection required to impose the desired stress on the test joint was calculated for each specimen, and these calculated stresses were corroborated for static deflection conditions at room temperature by use of strain gages attached to each test specimen. Then, the stresses were calculated for the dynamic and operating temperature conditions of each test in order to determine the actual specimen deflection to be used. The detailed procedure for obtaining the test deflection to be used for the stress reversal bending specimens is presented in Appendix II, Page 180.

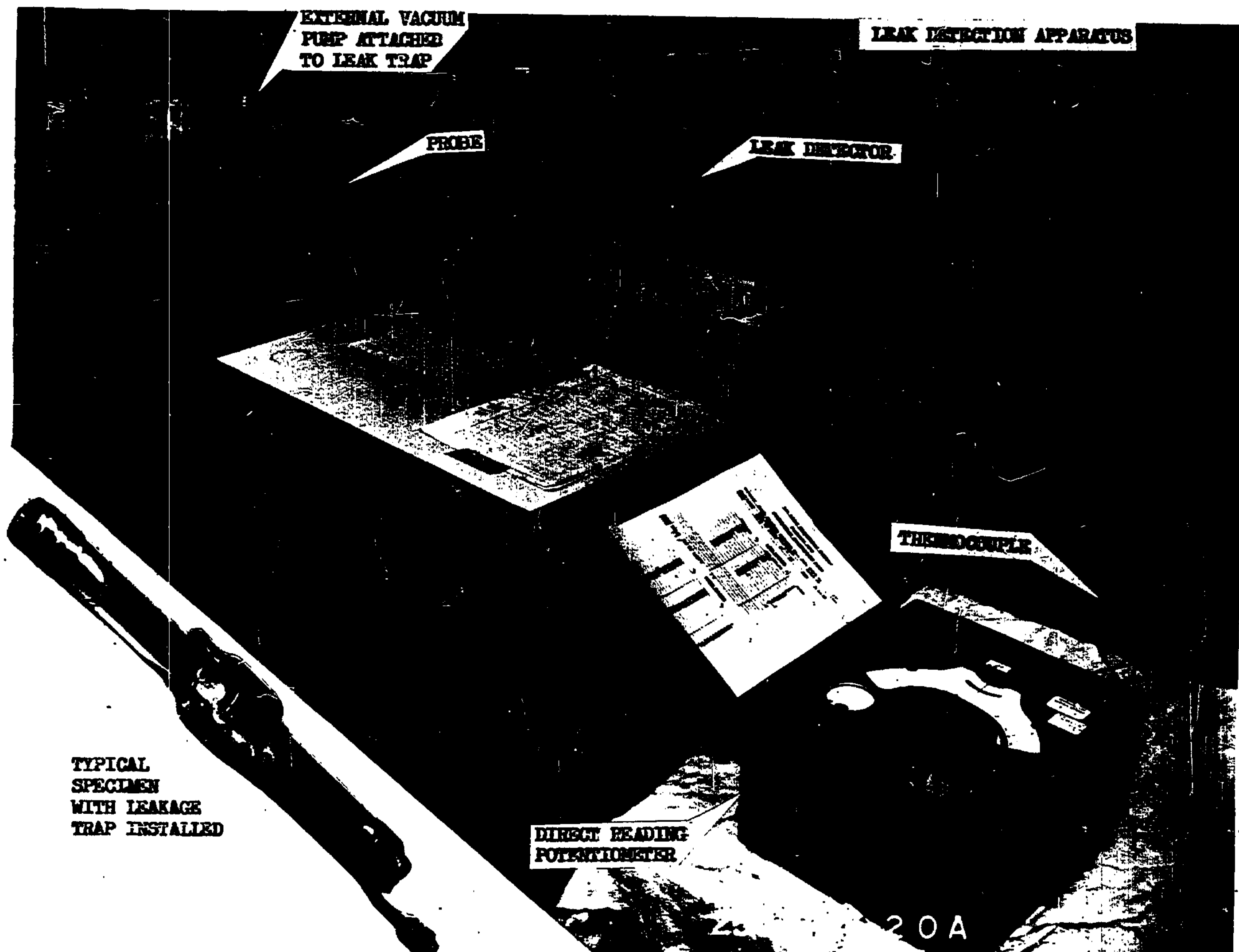
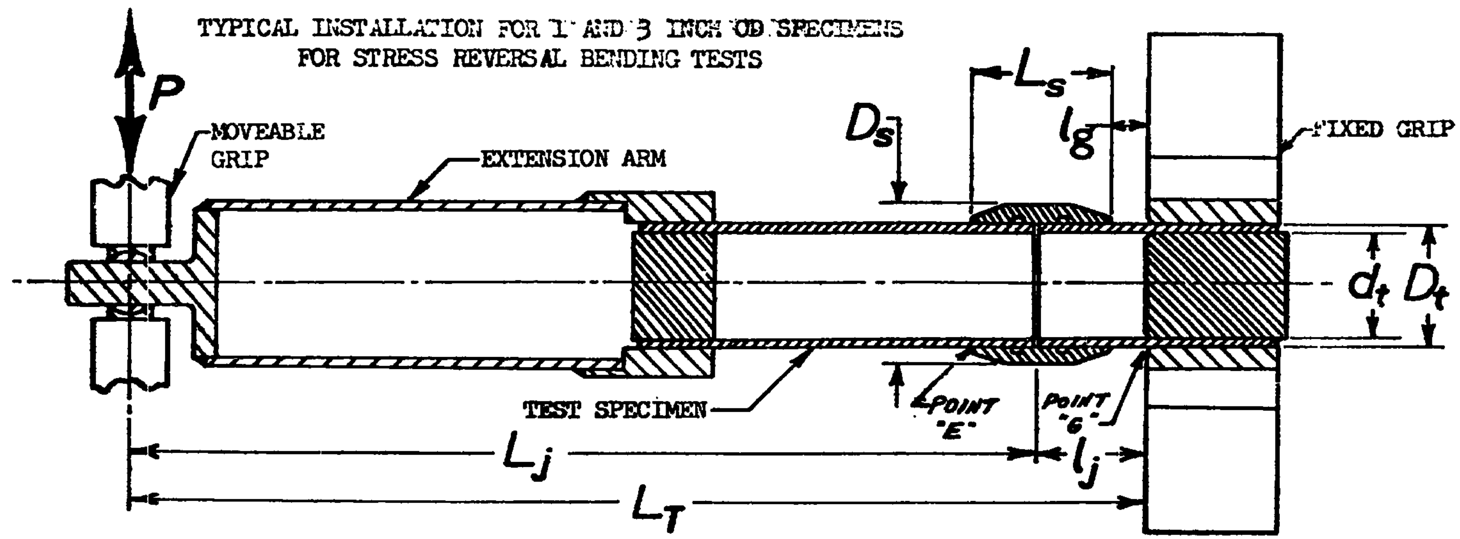

EXTERNAL VACUUM
PUMP ATTACHED
TO LEAK TRAP
LEAK DETECTION APPARATUS
PROBE
LEAK DETECTOR
THERMOCOUPLE
TYPICAL
SPECIMEN
WITH LEAKAGE
TRAP INSTALLED
DIRECT READING
POTENTIOMETER
20A

Figure 69


CHAMBER USED FOR HIGH
HIGH PRESSURE RUPTURE
TEST CHAMBER
200F - 600F
KEEP CLEAR
HIGH PRESS.
&
TEMP. BURST
4-22-63 2557-95-20 D

Figure 70

TYPICAL INSTALLATION FOR 1 AND 3 INCH OD SPECIMENS
FOR STRESS REVERSAL BENDING TESTS

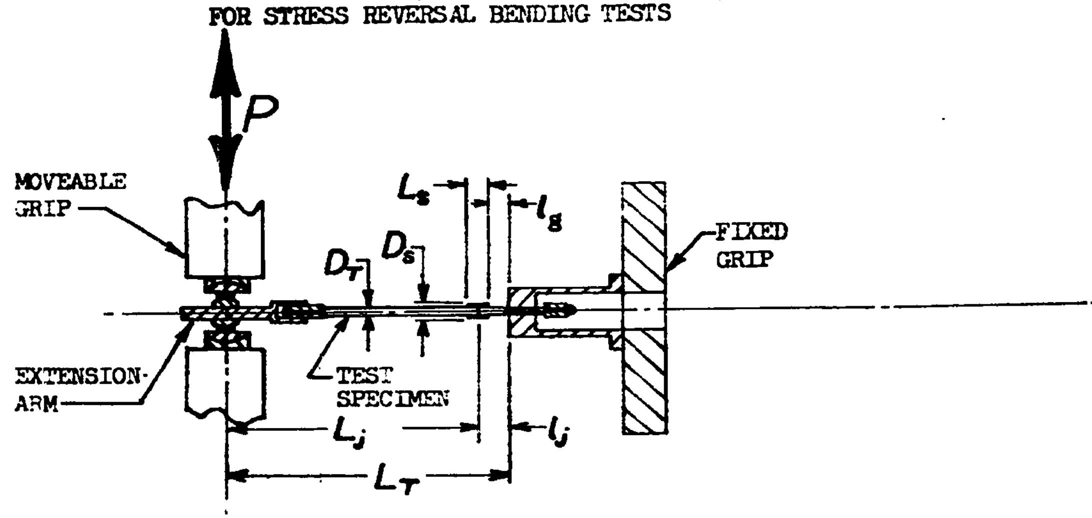


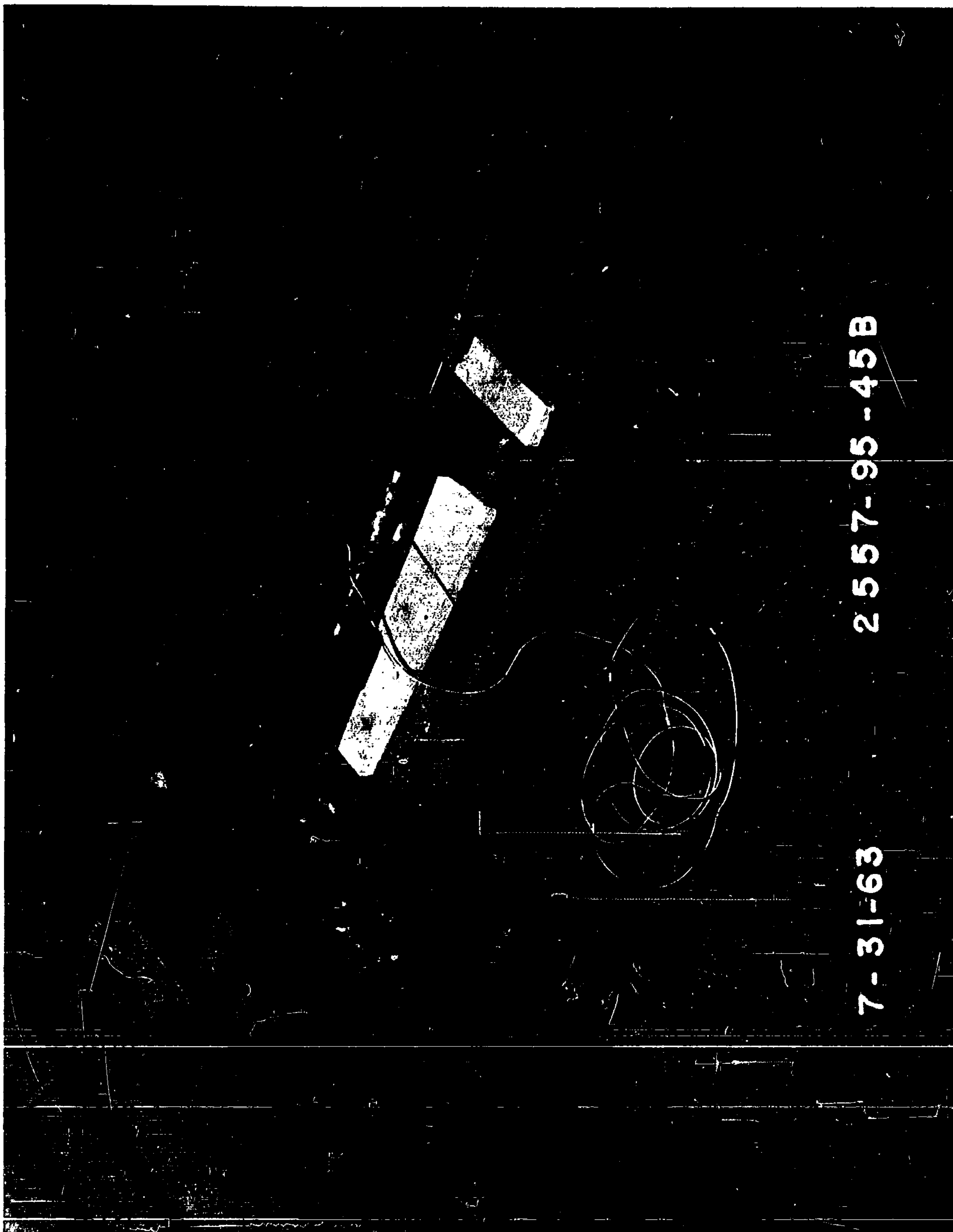
TEST SPECIMEN TUBING					TEST SPECIMEN DIMENSIONS				TEST INSTALLATION DIMENSIONS			
MATERIAL	TENSILE YIELD STR. AT -320F	TENSILE YIELD STR. AT MAXIMUM TEST TEMP.	MAXIMUM TEST TEMPERATURE	TYPE OF JOINT	TUBING O.D.	TUBING I.D.	SLEEVE O.D.	SLEEVE LENGTH	OVERALL BENDING TO JOINT	BEAM LENGTHS TO GRIP	END OF SLEEVE TO GRIP	JOINT TO GRIP
	psi	psi			D_t	d_t	D_s	L_s	L_j	L_T	l_g	l_j
AISI 347 STAINLESS STEEL	40,500	26,000	200 F	BRAZED	1.000	0.834	1.250	1.500	11	$11\frac{7}{8}$	1/8	$\frac{7}{8}$
				WELDED			1.060	1.000 (1)			3/8	
				BRAZED	3.000	2.500	3.720	3.335	$21\frac{3}{8}$	24	61/64	$2\frac{5}{8}$
				WELDED			— (2)	— (2)			— (2)	
AM 350 STAINLESS STEEL	81,000	44,000	600F	BRAZED	0.250	0.166	0.400	0.559	$7\frac{3}{16}$	7.550	0.083	0.3625
				WELDED			0.280	0.500 (1)		$7\frac{9}{16}$	1/8	3/8
				BRAZED	1.000	0.732	1.304	1.500	11	$11\frac{7}{8}$	1/8	$\frac{7}{8}$
				WELDED			— (2)	— (2)			— (2)	
RENE' 41	115,000	75,000	1500F	BRAZED	0.125	0.105	0.188	0.500	$7\frac{3}{16}$	$7\frac{1}{2}$	1/16	$\frac{5}{16}$
				WELDED			0.145	0.375 (1)			1/8	
				BRAZED	1.000	0.870	1.230	1.500	11	$11\frac{7}{8}$	1/8	$\frac{7}{8}$
				WELDED			1.070	1.000 (1)			3/8	
6061 ALUMINUM	19,000	16,000	200F	WELDED	0.250	0.152	— (2)	— (2)	$7\frac{3}{16}$	$7\frac{13}{16}$	— (2)	5/8
					1.000	0.884	— (2)	— (2)	11	$11\frac{7}{8}$	— (2)	7/8

(1) ALL WELDED JOINTS WERE SINGLE BUTT WELD, JOINING BOTH SLEEVE AND ENDS OF TUBING.
(2) NO SLEEVE USED.

Figure 71

FIGURE 72.
TYPICAL INSTALLATION FOR 1/8 AND 1/4 INCH OD SPECIMENS
FOR STRESS REVERSAL BENDING TESTS




7-31-63
2557-95-45B

The stress reversal bending tests were conducted at a bending stress cycling rate of approximately 1800 cpm. The specimens were pressurized with gaseous nitrogen to 23 psig for failure detection during testing. The test instrumentation was set up so that a drop in the specimen pressure of 5 psig denoted failure and activated a pressure switch to stop the test.

Temperature Shock and Pressure Impulse

The specimens were subjected to temperature shock by alternately exposing the test joint portion of the specimen to a blast of air which had been heated to the required test temperature and then to a spray of liquid nitrogen at -320 F which was released from suitably placed spray nozzles. Twenty-five (25) cycles of temperature shock were imposed on the test specimen within a fifteen (15) minute period. During this period of cyclic temperature shock the test specimens were also subjected to internal pressure impulse cycling from zero to 150 percent of the maximum system operating pressure. The test temperature and pressure conditions were as shown in Table XVIII. The procedure for the temperature shock tests which were to have been conducted on the Rene' 41 alloy specimens differed only in that the blast of heated air was replaced by a flame from suitably placed propane burners. The installation for the combined temperature shock and pressure impulse tests with heated air is shown in Figure 74. The specimens were required to complete this test without rupture or leakage.

Pressure impulse tests at constant temperature were conducted in addition to the combined temperature shock and pressure impulse tests described in the preceding paragraph. The constant temperature pressure impulse tests were conducted at -320 F, and also at the maximum design operating temperature for each type of material. The specimens were required to withstand 10,000 pressure impulse cycles at a given test temperature without rupture or leakage.

Two types of pressure impulse patterns were used by which the pressure was cycled from zero psig (nominal) to 150 percent of the maximum system operating pressure. Each pressure pattern incorporated a dwell at 100 percent of the maximum system operating pressure. One pattern was a "spike" type similar to the classic water hammer where a high pressure pulse is superimposed on the system pressure. This pattern was used with hydraulic fluid as the pressurizing medium, and could be cycled at rates of 35 to 40 cpm or better. The second type of impulse pattern consisted of a "square" wave pattern incorporating a dwell at system pressure. This pattern was used with either gas or hydraulic fluid as the pressurizing medium. With the square wave pattern the cycle rate was greatly reduced. Square wave pressure impulse testing was conducted at rates from 1.5 cpm to 10 cpm. The nominal zero pressure level in the square wave pattern is the pre-charge pressure of the gas system, which can be considerable. For example, for the tests where the peak pressure was 15,000 psig the nominal zero pressure level was approximately 2200 psig. Traces of typical pressure impulse cycles obtained during testing are reproduced in Figures 75 and 76 for each

Figure 74. THERMAL SHOCK TESTING.

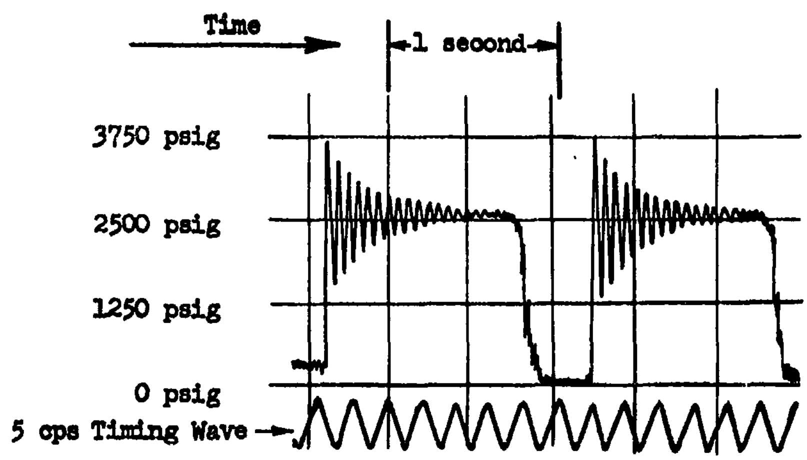
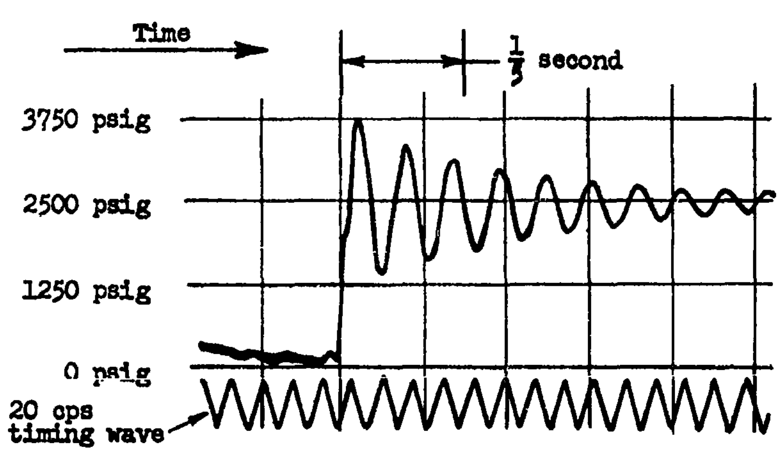
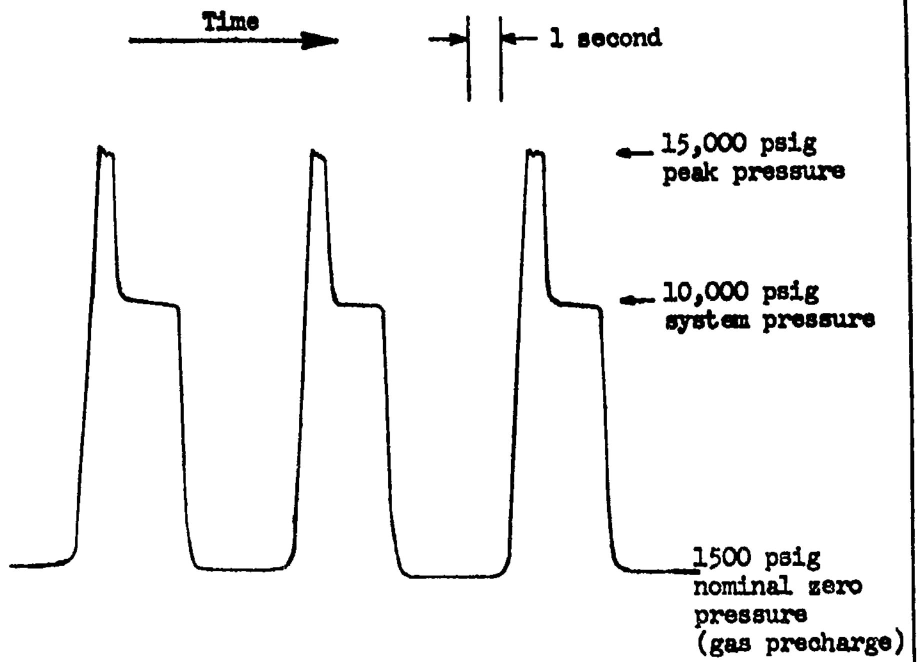


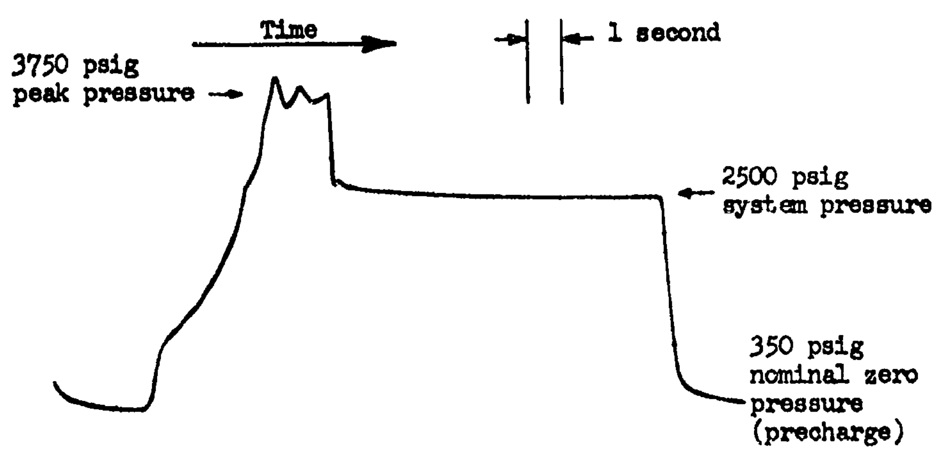
Figure 75.

SPIKE PRESSURE IMPULSE PATTERN WITH ORONITE 8200 HYDRAULIC FLUID USED IN TEMPERATURE SHOCK TEST OF AISI 347 STAINLESS STEEL TUBE JOINTS. CYCLE RATE 40 CPM.





(a) SQUARE WAVE PRESSURE IMPULSE PATTERN WITH ORONITE 8200 HYDRAULIC FLUID USED FOR 600 F TESTING OF AM 350 STAINLESS STEEL TUBE JOINTS. CYCLE RATE 9 CPM.



(b) SQUARE WAVE PRESSURE IMPULSE PATTERN WITH GASEOUS NITROGEN PRESSURIZING FLUID USED FOR -320 F TESTING OF AISI 347 STAINLESS STEEL TUBE JOINTS. CYCLE RATE 3 CPM.

Figure 76.

type of impulse pattern. The pressurizing fluids, impulse pattern, and cycle rate for the thermal shock and for the pressure impulse tests are given in Table XIX.

Vibration

Two configurations of tests were conducted during the vibration testing of the specimens for this program. One set of specimens of the various types of joints were tested as indeterminate beams with end fixity at both ends of the specimens. A second set of specimens was tested as a simple beam configuration with the specimen ends attached to the test fixture by flexible mountings. Vibration test installations are shown in Figures 77 and 78.

The specimens were subjected to a vibratory amplitude sufficient to produce in the specimen at the test joint a dynamic stress equivalent to 75 percent, maximum, of the yield strength of the specimen tubing at the testing temperature. The particular frequencies used for each specimen are given in Tables XXVIII, page 193, and Table XXIX, page 213, in Appendix III. Each specimen was strain gaged and optical displacement indicating instrumentation was also used to determine the specimen test stress.

Theoretical calculations were made for each material, each tube size, and each test temperature to determine the installed specimen length and the desired displacement. The derivation of the equations used for these calculations, sample calculations, and the summary of the vibration test results are presented in Appendix III, page 188.

The vibration tests were conducted in the following manner. Each specimen was mounted in the test fixture, heated to the testing temperature and stabilized at this temperature. Then, utilizing a low input vibratory forcing function, a frequency search from 10 to 2000 cps was performed to determine acceptance and response modes, and transmissibilities at resonant conditions. Each specimen was next excited at the test temperature using sufficient input amplitude at the fundamental response frequency of the specimen to produce the desired stress at the test joint. The test specimens were vibrated for 2,000,000 cycles unless failure occurred sooner. When the response mode of the specimen changed during the test, and there was no evidence of test specimen failure, the frequency and/or the input forcing function were changed to maintain the desired stress level at the test joint.

Repeated Assembly

This test was not conducted because the tube joining processes which were developed under this program were found not to be amenable to the specified repeated assembly procedure; that is, that no additional braze alloy could be added to the joint during the reassembly operation.

TABLE XIX. PRESSURE IMPULSE TEST FLUIDS, IMPULSE PATTERNS, AND TESTING RATES

TUBE MATERIAL	TYPE OF JOINT	MAXIMUM IMPULSE PRESSURE psig	TEMPERATURE SHOCK TEST			PRESSURE IMPULSE TEST AT -320 F			PRESSURE IMPULSE TEST AT 200 F			PRESSURE IMPULSE TEST AT 600 F		
			TEST FLUID	IMPULSE PATTERN	IMPULSE RATE cpm	TEST FLUID	IMPULSE PATTERN	IMPULSE RATE cpm	TEST FLUID	IMPULSE PATTERN	IMPULSE RATE cpm	TEST FLUID	IMPULSE PATTERN	IMPULSE RATE cpm
AISI Type 347 Stainless Steel	Brazed	3750	Oronite 8200	Spike	40	N_2	Square Wave	3	Oronite 8200	Spike	34.5	--	--	--
	Welded	3750	Oronite 8200	Spike	41.5	N_2	Square Wave	3	Oronite 8200	Spike	36.2	--	--	--
AM 350 Stainless Steel	Brazed	15,000	Oronite 8200	Square Wave	10	He	Square Wave	1.5	--	--	--	Oronite 8200	Square Wave	9
	Welded	15,000	Oronite 8200	Square Wave	10	He	Square Wave	1.5	--	--	--	Oronite 8200	Square Wave	9.5
6061-T6 Aluminum Alloy	Welded	1500	Oronite 8200	Spike	40	N_2	Square Wave	4	Oronite 8200	Spike	34.0	--	--	--

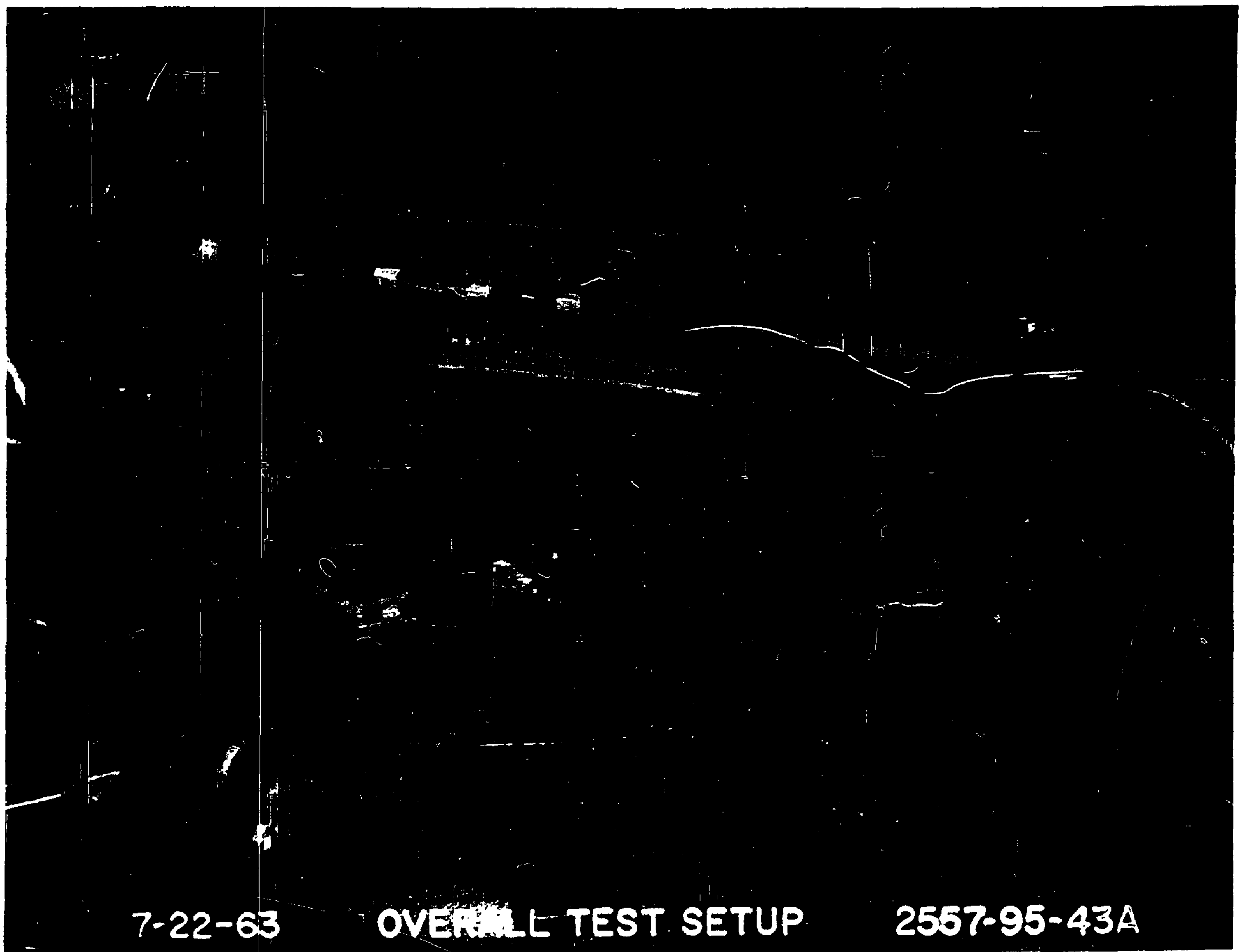


Figure 77. Indeterminate Beam Configuration Set-up for Vibration Testing at 200 F

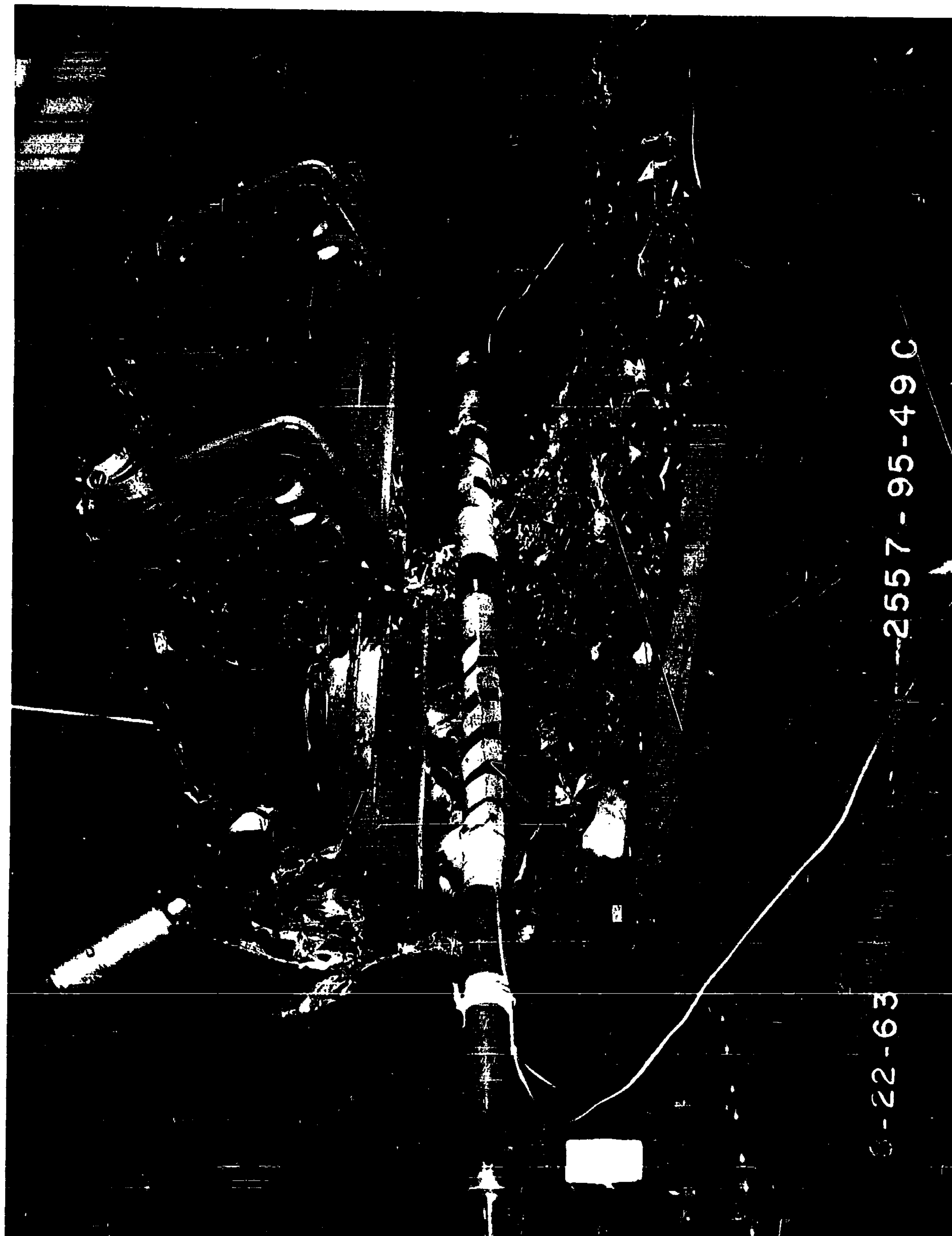


Figure 78. Simple Support Beam Configuration Set-up for Vibration Testing at 600 F

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REFERENCES

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APPENDIX I

DETAIL RESULTS OF QUALIFICATION TESTS

TABLE XX. TEST RESULTS FOR AISI TYPE 347 STAINLESS STEEL SPECIMENS WITH BRAZED JOINTS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
1	7	1 x 0.083	Burst at 200 F	6-19-63	Rupture at 12,200 psig	Yes
2	17	1 x 0.083	Stress Reversal Bending at -320 F	8- 5-63	No Failure. Completed 205,000 cycles at stress of 30,000 psi	Yes
3	19	1 x 0.083	Stress Reversal Bending at 200 F	7-24-63	Failure at 71,500 cycles at stress of 19,900 psi	No
4	11	1 x 0.083	Temperature Shock at -320F to 200F	7-31-63	No Failure. Completed 25 thermal cycles with 622 pressure impulse cycles	Yes
5	8	1 x 0.083	Pressure Impulse at -320 F	7-10-63 7-17-63	No Failure. Completed 10,126 pressure cycles	Yes
6	9	1 x 0.083	Pressure Impulse at 200 F	6-24-63	No Failure. Completed 10,475 pressure cycles	Yes
112	15	1 x 0.083	Proof and Leak at -320 F and 200 F	6-27-63 7-10-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200F Indeterminate Beam		No Failure. Completed 2 x 10^6 cycles at 8,030 psi stress	Yes
113	16	1 x 0.033	Proof and Leak at -320 F and 200 F	6-27-63 7-10-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200F Simple Beam		Failure at 269,000 cycles at 19,500 psi stress	No

TABLE XX1. TEST RESULTS FOR AISI TYPE 347 STAINLESS STEEL SPECIMENS WITH WELDED JOINTS

FM Lab. Specimen Number	[illegible] Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
31	5	1 x 0.083	Burst at 200 F	4-29-63	Rupture at 12,400 psig	Yes
32	13	1 x 0.083	Stress Reversal Bending at -320 F	8- 5-63	No Failure. Completed 205,000 cycles at stress of 30,700 psi	Yes
33	14	1 x 0.083	Stress Reversal Bending at 200 F	7-23-63	No Failure. Completed 205,000 cycles at stress of 19,500 psi	Yes
34	17	1 x 0.083	Temperature Shock at -320F to 200F	8- 1-63	No Failure. Completed 25 thermal cycles with 633 pressure impulse cycles	Yes
35	11	1 x 0.083	Pressure Impulse at -320 F	7- 5-63 7- 9-63	No Failure. Completed 10,051 pressure impulse cycles	Yes
36	12	1 x 0.083	Pressure Impulse at 200 F	5- 1-63	No Failure. Completed 11,929 pressure impulse cycles	Yes
37	2	3 x 0.250	Burst at 200 F	4-30-63	Rupture at 12,800 psig	Yes
38	[illegible]	3 x 0.250	Stress Reversal Bending at -320 F	7-31-63 8-21-63	No Failure. Completed 204,000 cycles at stress of 30,900 psi	Yes
39	5	3 x 0.250	Stress Reversal Bending at 200 F	7-26-63 7-30-63	No Failure. Completed 212,700 cycles at stress of 19,500 psi	Yes
78	19	1 x 0.083	Proof and Leak at -320 F and 200 F	4-16-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200F Indeterminate Beam		No Failure. Completed 2 x 10^6 cycles at 9,070 psi stress	Yes

TABLE XXI. TEST RESULTS FOR AISI TYPE 347 STAINLESS STEEL SPECIMENS WITH WELDED JOINTS (Continued)

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
79	20	1 x 0.083	Proof and Leak at -320 F and 200 F	4-16-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200 F		Not tested	—
80	21	1 x 0.083	Proof and Leak at -320 F and 200 F	4-16-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200 F Simple Beam		No Failure. Completed 2×10^6 cycles at 19,500 psi stress	Yes
None	Not Noted	1 x 0.083	Rupture at 200 F	2-13-63	Rupture at 12,800 psig	(a)
None	Not Noted	3 x 0.250	Rupture at 200 F	2-15-63	Rupture at 12,600 psig	(a)

(a) Development specimen, tested for information only.

TABLE XXII. TEST RESULTS FOR AM 350 STAINLESS STEEL SPECIMENS WITH BRAZED JOINTS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
10	3	1/4 x 0.042	Burst at 600 F	6-19-63	No Failure at 20,000 psig	Yes
11	2	1/4 x 0.042	Stress Reversal Bending at -320 F	8- 9-63	No Failure. Completed 205,000 cycles at stress of 60,000 psi	Yes
12	1	1/4 x 0.042	Stress Reversal Bending at 600 F	8- 8-63	Failure at 156,500 cycles at stress of 32,600 psi	No
13	2	1 x 0.134	Burst at 600 F	6-19-63	No Failure at 20,000 psig	Yes
14	13	1 x 0.134	Stress Reversal Bending at -320 F	8-12-63 8-13-63	Failure at 70,100 cycles at stress of 59,700 psi	No
15	10	1 x 0.134	Stress Reversal Bending at 600 F	7-24-63	Failure at 80,000 cycles at stress of 34,000 psi	No
16	5	1 x 0.134	Temperature Shock at -320F to 600F	7-29-63	No Failure. Completed 25 thermal cycles with 156 pressure impulse cycles	Yes
17	7	1 x 0.134	Pressure Impulse at -320 F	8- 7-63 8-16-63	No Failure. Completed 10,120 pressure impulse cycles	Yes
18	6	1 x 0.134	Pressure Impulse at 600 F	7-19-63 7-22-63	No Failure. Completed 10,008 pressure impulse cycles	Yes
88	10	1/4 x 0.035	Burst at 600 F	5- 6-63	No Failure at 20,000 psig	(a)

(a) Development specimen, tested for information only.

TABLE XXII. TEST RESULTS FOR AM 350 STAINLESS STEEL SPECIMENS WITH BRAZED JOINTS (Continued)

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
119	11	1 x 0.134	Proof and Leak at -320 F and 600 F	6-28-63 7-10-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 600F Simple Beam		No Failure. Completed 2 x 10^6 cycles at 33,000 psi stress	Yes
120	9	1 x 0.134	Proof and Leak at -320 F and 600 F	6-28-63 7-10-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 600F Indeterminate Beam		No Failure. Completed 2 x 10^6 cycles at 17,430 psi stress	Yes

TABLE XXIII. TEST RESULTS FOR AM 350 STAINLESS STEEL SPECIMENS WITH WELDED JOINTS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
40	None	1/4 x 0.042	Burst at 600 F	4-29-63	No Failure at 20,000 psig	Yes
41	11	1/4 x 0.042	Stress Reversal Bending at -320 F	8-10-63	No Failure. Completed 205,000 cycles at stress of 59,100 psi	Yes
42	12	1/4 x 0.042	Stress Reversal Bending at 600 F	8- 9-63	Failure at 91,800 cycles at stress of 32,600 psi	No
43	5	1 x 0.134	Burst at 600 F	4-29-63	No Failure at 20,000 psig	Yes
44	26	1 x 0.134	Stress Reversal Bending at -320 F	8- 6-63	Failure at between 192,000 and 205,000 cycles at 61,000 psi stress (specimen approved)	Yes
45	27	1 x 0.134	Stress Reversal Bending at 600 F	7-25-63	Failure at between 94,400 and 183,000 cycles at 34,600 psi (automatic shutoff failed)	No
46	22	1 x 0.134	Temperature Shock at -320F to 600F	7-29-63	No Failure. Completed 25 thermal cycles with 237 pressure impulse cycles	Yes
47	20	1 x 0.134	Pressure Impulse at -320 F	8- 7-63 8-16-63	No Failure. Completed 10,120 pressure impulse cycles	Yes
48	21	1 x 0.134	Pressure Impulse at 600 F	7-19-63 7-22-63	No Failure. Completed 10,008 pressure impulse cycles	Yes
89	19	1 x 0.134	Burst at 600 F	5-20-63	No Failure at 20,000 psig	Yes

TABLE XXIII. TEST RESULTS FOR AM 350 STAINLESS STEEL SPECIMENS WITH WELDED JOINTS (Continued)

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
100	28	1 x 0.134	Proof and Leak at -320 F and 600 F	6-25-63 6-26-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 600F Indeterminate Beam		No Failure. Completed 2×10^6 cycles at 16,600 psi stress	Yes
101	29	1 x 0.134	Proof and Leak at -320 F and 600 F	6-25-63 6-26-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 600F		Not tested.	
102	30	1 x 0.134	Proof and Leak at -320 F and 600 F	6-25-63 6-26-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 600F Simple Beam		No Failure. Completed 2×10^6 cycles at 33,000 psi stress	Yes

TABLE XXIV. TEST RESULTS FOR RENE' 41 ALLOY SPECIMENS WITH BRAZED JOINTS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
19	5	1/8 x 0.010	Burst at 1500 F	6-14-63	No Failure at 8,000 psig	Yes
20	1	1/8 x 0.010	Stress Reversal Bending at -320 F	8-19-63	Failure at 25,000 cycles at stress of 86,250 psi	(a)
21	2	1/8 x 0.010	Stress Reversal Bending at Room Temperature	8-16-63	Failure at 58,500 cycles at stress of 67,100 psi	(b)
22	8	1/8 x 0.010	Stress Reversal Bending at 1500 F	8-20-63	Failure at 23,200 cycles at stress of 56,000 psi	(c)
105	3	1/8 x 0.010	Burst at 1500 F	6-19-63	No Failure at 8,000 psig	Yes

(a) During initial set-up at room temperature this specimen was inadvertently stressed to 87,400 psi.

(b) Specimen shows evidence of damage which may have contributed to failure.

(c) During initial set-up at room temperature this specimen was inadvertently stressed to 84,700 psi. Brazed joint did not fail, parent tubing cracked at edge of fixed support grip.

TABLE XXV. TEST RESULTS FOR RENE' 41 ALLOY SPECIMENS WITH WELDED JOINTS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
49	11	1/8 x 0.010	Burst at 1500 F	5-14-63	Damaged during Leak Test	—
50	20	1/8 x 0.010	Stress Reversal Bending at -320 F	8-21-63	Failure at 16,150 cycles at stress of 88,500 psi	(a)
51	21	1/8 x 0.010	Stress Reversal Bending at 1500 F	8-21-63	Failure at 125,700 cycles at 54,500 psi stress	(a)
52	22	1/8 x 0.010	Stress Reversal Bending at Room Temperature	8-20-63	Specimen was damaged when test fixture broke at 19,750 cycles at stress of 62,700 psi, test discontinued.	—
53	5	1 x 0.065	Burst at 1500 F	4-26-63 4-29-63	Failed during Leak Test at 1500 F	(b)
94	6	1/8 x 0.010	Burst at 1500 F	5-22-63	Failure in parent tubing at 7,000 psig	(b)
130	17	1/8 x 0.010	Burst at 1500 F	8-17-63 8-19-63	Distortion in parent tubing during proof test	—
131	18	1.8 x 0.010	Burst at 1500 F	8-20-63	No Failure at 8,000 psig	Yes

(a) Welded joint did not fail. Parent tubing cracked at edge of fixed support grip.

(b) Development specimen, tested for information only.

TABLE XXVI. TEST RESULTS FOR 6061 [illegible] ALLOY SPECIMENS [illegible] JOINTS

[illegible] Lab. Specimen Number	[illegible] Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks	Joint Acceptable to Qualification Test Requirements
67	4	1 x 0.058	Burst at 200 F	6-18-63	Leak detected at 1,000 psig	(a)
68	9	1 x 0.058	Stress Reversal Bending at -320 F	8- 2-63	No Failure. Completed 208,000 cycles at stress of 14,900 psi	Yes
69	14	1 x 0.058	Stress Reversal Bending at 200 F	8- 2-63	Failure at 27,000 cycles at stress of 11,900 psi	No
70	17	1 x 0.058	Temperature Shock at -320F to 200F	8- 1-63	No Failure. Completed 25 thermal cycles with 600 pressure impulse cycles	Yes
71	13	1 x 0.058	Pressure Impulse at -320 F	8- 9-63 8-13-63	No Failure. Completed 10,500 pressure impulse cycles	Yes
72	15	1 x 0.058	Pressure Impulse at 200 F	8- 2-63 8- 3-63	No Failure. Completed 10,005 pressure impulse cycles	Yes
111	10	1 x 0.058	Burst at 200 F	6-24-63	No Failure at 2,000 psig	Yes
121	21	1 x 0.058	Proof and Leak at -320 F and 200 F	7-23-63 7-24-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200F Simple Beam		Failure at 137,500 cycles at 12,000 psi stress	No (b)
122	22	1 x 0.058	Proof and Leak at -320 F and 200 F	7-23-63 7-24-63	No Leakage or Distortion, accepted for vibration test.	Yes
			Vibration at 200F Indeterminate Beam		No Failure in test joint. Failure in parent tube at grip at 1.5×10^6 cycles at a (calculated) stress of 62,500 psi (c)	Yes

(a) Development specimen, tested for information only.
(b) This specimen previously had completed without failure 2×10^6 cycles at 2,400 psi stress.
(c) Stress calculated from observed deflection, strain gages lost during initial loading.

TABLE XXVII. RESULTS OF TESTS OF PARENT TUBING SPECIMENS

FM Lab. Specimen Number	MM Lab. Specimen Number	Specimen Tube Size (inches) OD x Wall	Specimen Tubing Material	Designated Test Description and Temperature	Date of Testing	Test Results and Remarks
None	None	1 x 0.083	AISI Type 347 Stainless Steel	Rupture at 200 F	2-12-63	Rupture at 12,400 psig
1-EX.	None	1/8 x 0.010	Rene' 41 Alloy	Proof and Rupture at Room Temperature	3-18-63	Rupture at 22,000 psig (a)
2-EX.	None	1/8 x 0.010	Rene' 41 Alloy	Proof and Rupture at Room Temperature	3-18-63	Rupture at 28,000 psig (b)
3-EX.	None	1/8 x 0.010	Rene' 41 Alloy	Proof and Rupture at 1500 F	3-26-63	Rupture at 14,000 psig (a)
4-EX.	None	1/8 x 0.010	Rene' 41 Alloy	Proof and Rupture at 1500 F	3-27-63	No Failure at 17,000 psig (b)
86	1	1 x 0.065	Rene' 41 Alloy	Burst at Room Temperature	5- 3-63	Rupture at 16,000 psig
87	2	1 x 0.065	Rene' 41 Alloy	Burst at 1500 F	5- 8-63	Rupture at 8,000 psig

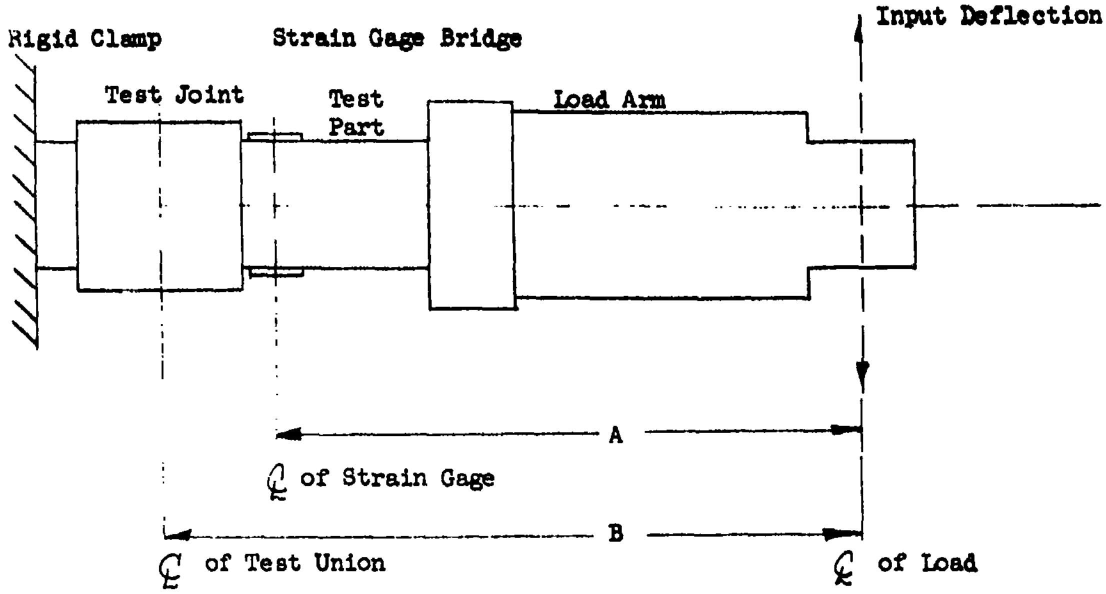
(a) Specimen in solution annealed and as-welded (end plugs) condition.

(b) Specimen in solution annealed condition, end plugs welded on, then exposed at 1500 F for one hour prior to pressure testing.

APPENDIX II

CALCULATIONS FOR STRESS REVERSAL BENDING TEST

I. Sketch of Typical Stress Reversal Bending Test Specimen Installed for Test.



II. The stress reversal bending tests were performed utilizing a mechanical flexure fixture of an eccentric type design that maintained a specified deflection.

III. Each specimen for the stress reversal bending test was instrumented with strain gages mounted in a bending bridge configuration. Strains measured by an SR-4 strain indicator were used to obtain the test stresses.

IV. The following assumptions were made to facilitate calculations:

a. The material was homogeneous and remained within the elastic range; i.e., $S = E\epsilon$ was valid.
b. The effect of stress concentrations were negligible.
c. A constant cross section was maintained and this cross section was that of the tubing joined; i.e. A straight piece of tubing with no discontinuities (such as the test joint) was being tested.
d. Strain was not a function of temperature; i.e. $\frac{d\epsilon}{dT} = 0$. However, $E = f(T)$ and therefore, the modulus at the test temperature must necessarily be used.

V. The following technique was employed:

a. The strain was read on an SR-4 strain indicator which in turn was used to calibrate a direct printing oscilloscope (Visicorder, Minnieapolis-Honeywell). The visicorder record was used to obtain dynamic strain readings (dynamic increase caused by inertia forces, fixture tolerances, etc.) and the flexure cycle rate.

b. $S = \frac{Mc}{I} = \frac{Plc}{I} = E\epsilon$

$(\epsilon = \frac{\epsilon_{IND.}}{2}$ for NAA Type B-2-2 Bending Bridge)

c. The strain gages are mounted Δl inches from the union centerline where the stress is desired and a transfer of stress must result.

$S_{S.G.} = \frac{P l_{S.G.} c}{I}$; $S_{UNION} = \frac{P l_{UNION} c}{I}$ if the assumptions in IV are valid.

$\therefore \quad S_{UNION} = S_{S.G.} \frac{l_{UNION}}{l_{S.G.}}$

Let $k = \frac{l_{UNION}}{l_{S.G.}} = \frac{B}{A}$ (see sketch)

Then, $S_{UNION\,℄} = kE\epsilon$

VI. Sample Calculation:

Fluid Mechanics Specimen No. 68
6061-T6 Aluminum Alloy, 1" O.D. x 0.058" wall, welded joint.
75% of Tubing "as welded" Yield Strength at -320 F.

$k = \frac{℄ \text{ of load to } ℄ \text{ of union}}{℄ \text{ of load to } ℄ \text{ of strain gage}} = \frac{11.125}{10.525}$; $S_{y-320} = 19{,}000$ psi

$E_{-320} = 11.5 \times 10^6$ psi

$kE = 12.15 \times 10^6$ psi

S_{R-4} Zero = 15,260 $\frac{\mu\text{-in.}}{\text{in.}}$

Fixture Deflection	North	South
Static Defelction	0.135 in.	0.145 in.
Δ SR-4 Static Reading	2190 $\frac{\mu\text{-in.}}{\text{in.}}$	2160 $\frac{\mu\text{-in.}}{\text{in.}}$

Dynamic Increase From Visicorder Trace		
	11.9 %	12.0%
Δ SR-4 Dynamic Reading	2450	2420
ϵ Dynamic $\frac{\mu\text{-in.}}{\text{in.}}$	1225	1210
$S = kE\epsilon$ Dynamic Test stress	14,900 psi	14,700 psi

$S_{Desired} = 0.75 \times 19{,}000$ psi $= 14{,}250$ psi

SUMMARY OF RESULTS OF ANALYSIS OF STRESSES
AT FITTING SLEEVE AND FIXED GRIP END
FOR STRESS REVERSAL BENDING TEST SPECIMENS

Stress Analysis Specimen Number	Specimen Tubing Material	Tubing Size		Type of Joint	Bending Load "P"	Stress at Joint Center-line	Stress at Edge of Sleeve	Stress at Fixed Grip	Maximum Stress in Braze Alloy
		OD	ID						
		inch	inch		Pounds	psi	psi	psi	psi
6	Type 347	1.000	0.834	Brazed	90	19,500	18,174	21,060	896
7	Stain-less	1.000	0.834	Welded	90	19,500	18,623	21,060	—
1	Steel	3.000	2.500	Brazed	1,251	19,500	17,979	21,899	1,223
2		3.000	2.500	Welded	1,251	19,500	—	21,899	—
10	AM 350	0.250	0.166	Brazed	5.66	33,000	31,614	34,650	1,570
11	Stain-less	0.250	0.166	Welded	5.66	33,000	31,845	34,716	—
8	Steel	1.000	0.732	Brazed	210	33,000	30,756	35,640	2,093
9		1.000	0.732	Welded	210	33,000	—	35,640	—
13		0.125	0.105	Brazed	0.75	56,250	54,281	58,669	907
14	Rene' 41	0.125	0.105	Welded	0.75	56,250	54,788	58,669	—
4	Alloy	1.000	0.870	Brazed	215	56,250	52,425	60,750	2,138
5		1.000	0.870	Welded	215	56,250	53,719	60,750	—
12	6061-T6	0.250	0.152	Welded	2.08	11,250	—	12,228	—
3	Aluminum Alloy	1.000	0.884	Welded	39.1	11,250	—	12,150	—

CALCULATION OF SECTIONS FOR ANALYSIS OF STRESSES
AT FITTING SLEEVE AND FIXED GRIP END
FOR STRESS REVERSAL BENDING TEST SPECIMENS

SPECIMEN NUMBER	OD	ID	$\frac{OD}{2} = R$	$\frac{ID}{2} = R_1$	R^4	R_1^4	$R^4 - R_1^4$	$.785(R^4 - R_1^4) = I$	c	$\frac{I}{c} = Z$
1 & 2	3.000	2.500	1.500	1.2500	5.0625	2.4414	2.6211	2.0576	1.5	1.3717
3	1.000	0.884	0.500	0.4420	6.2500×10^{-2}	3.8167×10^{-2}	2.4333×10^{-2}	1.9101×10^{-2}	0.5	3.8202×10^{-2}
4 & 5	1.000	0.870	0.500	0.4350	6.2500×10^{-2}	3.5807	2.6693	2.0954×10^{-2}	0.5	4.1908×10^{-2}
6 & 7	1.000	0.834	0.500	0.4170	6.2500×10^{-2}	3.0239	3.2261	2.5324×10^{-2}	0.5	5.0648×10^{-2}
8 & 9	1.000	0.732	0.500	0.3660	6.2500×10^{-2}	1.7944×10^{-2}	4.4556×10^{-2}	3.4976×10^{-2}	0.5	6.9952×10^{-2}
10 & 11	0.250	0.166	0.125	0.0830	2.4414×10^{-4}	4.7460×10^{-5}	1.9668×10^{-4}	1.5439×10^{-4}	0.1250	12.3152×10^{-4}
12	0.250	0.152	0.125	0.0760	2.4414×10^{-4}	3.3360×10^{-5}	2.1078×10^{-4}	1.6546×10^{-4}	0.1250	13.2368×10^{-4}
13 & 14	0.125	0.105	0.0625	0.0525	1.5259×10^{-5}	7.5970×10^{-6}	7.6620×10^{-6}	6.0147×10^{-6}	0.0625	96.2352×10^{-6}

CALCULATION OF "P" FOR ANALYSIS OF STRESSES
AT FITTING SLEEVE AND FIXED GRIP END
FOR STRESS REVERSAL BENDING TEST SPECIMENS

SPECIMEN NUMBER	SECTION Z	$S_b = .75F_{ty}$	$M_j = S_b \cdot Z$	L_j	$P = \frac{M_j}{L_j}$
1	1.3717	19,500	26,748	21.3750	1,251
2	1.3717	19,500	26,748	21.3750	1,251
3	3.8202×10^{-2}	11,250	430	11.0000	39.1
4	4.1908×10^{-2}	56,250	2,357	11.0000	215
5	4.1908×10^{-2}	56,250	2,357	11.0000	215
6	5.0648×10^{-2}	19,500	988	11.0000	90
7	5.0648×10^{-2}	19,500	988	11.0000	90
8	6.9952×10^{-2}	33,000	2,309	11.0000	210
9	6.9952×10^{-2}	33,000	2,309	11.0000	210
10	12.3125×10^{-4}	33,000	40.7	7.1875	5.66
11	12.3125×10^{-4}	33,000	40.7	7.1875	5.66
12	13.2368×10^{-4}	11,250	14.9	7.1875	2.08
13	96.2352×10^{-6}	56,250	5.4	7.1875	0.75
14	96.2352×10^{-6}	56,250	5.4	7.1875	0.75

CALCULATION OF STRESSES AT EDGE OF FITTING SLEEVE "E"
AND AT FIXED GRIP "G" FOR STRESS REVERSAL BENDING TEST SPECIMENS

SPECIMEN NUMBER	$K_1 = \frac{L_j - (\frac{L_s}{2})}{L_j}$	$K_3 = \frac{L_j + (\frac{L_s}{2})}{L_j}$	$K_4 = \frac{L_T}{L_j}$	$S_1 = K_1 S_2$	$S_4 = K_4 S_2$
1	$\frac{19.708}{21.375} = 0.922$	$\frac{23.042}{21.375} = 1.078$	$\frac{24.000}{21.375} = 1.123$	17,979	21,899
2	-	-	$\frac{24.000}{21.375} = 1.123$	-	21,899
3	-	-	$\frac{11.875}{11.000} = 1.080$	-	12,150
4	$\frac{10.250}{11.000} = 0.932$	$\frac{11.750}{11.000} = 1.068$	$\frac{11.875}{11.000} = 1.080$	52,425	60,750
5	$\frac{10.500}{11.000} = 0.955$	$\frac{11.500}{11.000} = 1.045$	$\frac{11.875}{11.000} = 1.080$	53,719	60,750
6	$\frac{10.250}{11.000} = 0.932$	$\frac{11.750}{11.000} = 1.068$	$\frac{11.875}{11.000} = 1.080$	18,174	21,060
7	$\frac{10.500}{11.000} = 0.955$	$\frac{11.500}{11.000} = 1.045$	$\frac{11.875}{11.000} = 1.080$	18,623	21,060
8	$\frac{10.250}{11.000} = 0.932$	$\frac{11.750}{11.000} = 1.068$	$\frac{11.875}{11.000} = 1.080$	30,756	35,640
9	-	-	$\frac{11.875}{11.000} = 1.080$	-	35,640
10	$\frac{6.3875}{7.1875} = 0.958$	$\frac{7.4875}{7.1875} = 1.042$	$\frac{7.5500}{7.1875} = 1.050$	31,614	34,650
11	$\frac{6.9375}{7.1875} = 0.965$	$\frac{7.4375}{7.1875} = 1.032$	$\frac{7.5625}{7.1875} = 1.052$	31,845	34,716
12	-	-	$\frac{7.8125}{7.1875} = 1.087$	-	12,228
13	$\frac{6.9375}{7.1875} = 0.965$	$\frac{7.4375}{7.1875} = 1.032$	$\frac{7.5000}{7.1875} = 1.043$	54,281	58,669
14	$\frac{7.0000}{7.1875} = 0.974$	$\frac{7.3750}{7.1875} = 1.026$	$\frac{7.5000}{7.1875} = 1.043$	54,788	58,669

NOTE: S_1 = stress at "E" (edge of sleeve): S_4 = stress at "G" (fixed grip)

CALCULATION OF MAXIMUM STRESS
IN BRAZE MATERIAL

SPECIMEN NUMBER	$M_3 = K_3M_2$	πL	R^2	πLR^2	$S_{BR} = \frac{M}{\pi LR^2}$
1	28,834	10.477	2.25	23.573	1,223
2	-	-	-	-	-
3	-	-	-	-	-
4	2,517	4.712	.2500	1.178	2,138
5	2,463	3.142	.2500	.7855	3,136
6	1,055	4.712	.2500	1.178	896
7	1,032	3.142	.2500	.7855	1,314
8	2,466	4.172	.2500	1.178	2,093
9	-	-	-	-	-
10	42.4	1.756	.0156	.027	1,570
11	42.0	1.570	.0156	.024	1,747
12	-	-	-	-	-
13	5.6	1.570	.00390	.00612	907
14	5.6	1.178	.00390	.00459	1,209

APPENDIX III

DETAIL CALCULATIONS AND RESULTS FOR VIBRATION TESTS

INDETERMINATE BEAM CONFIGURATION VIBRATION TESTS

TYPICAL EXAMPLE
INDETERMINATE BEAM

MATERIAL — 347 STAINLESS STEEL
LENGTH — 35.5 INCHES BETWEEN CLAMPS
WALL THICKNESS — 0.083 INCHES
OUTSIDE DIAMETER — 1.000 INCHES
MATERIAL DENSITY — 0.286 LB/IN³
TENSION MODULUS AT ROOM TEMP — 29.0×10^6 PSI
TENSION MODULUS AT 200°F — 27.9×10^6 PSI
TENSION YIELD AT 200°F — 26,000 PSI

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}}$$

$$\delta = \frac{w\ell^4}{384EI} = \frac{\pi(r_o^2 - r_i^2)D\ell^4}{384E\frac{\pi}{4}(r_o^2 - r_i^2)(r_o^2 + r_i^2)}$$

$$= \frac{D\ell^4}{96E(r_o^2 + r_i^2)} = \frac{(0.286)(35.5)^4}{(96)(27.9\times10^6)(0.424)}$$

$\delta = 4.0 \times 10^{-4}$ INCH (STATIC CALCULATED DEFLECTION)

f_{cc} = NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

$$f_{cc} = \frac{1}{2\pi}\sqrt{\frac{386}{4.0\times10^{-4}}}$$

f_{cc} = 156 CPS

f_{ss} = NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

$$f_{ss} = \frac{f_{cc}}{\sqrt{5}} = \frac{156}{2.24}$$

f_{ss} = 69.7 cps.

f_e = EXPERIMENTALLY MEASURED NATURAL FREQUENCY

f_e = 160 CPS.

RELATIONSHIP BETWEEN DEFLECTION COEFFICIENT & FREQ.

$$\left(\frac{160}{69.7}\right)^2 = \frac{5}{x}$$

$$x = 0.95$$

$$\delta = \frac{0.95\, w l^4}{384\, EI}$$

$$\delta = \leq \delta = \frac{5 w l^4}{384\, EI} - \frac{M l^2}{8 EI}$$

$$M = \frac{w l^2}{11.85}$$

ACTUAL DEFLECTION (1 "g" STATIC)

$$\delta = x\delta = (0.95)(4.0 \times 10^{-4})$$

$$\delta = 3.8 \times 10^{-4} \text{ INCH}$$

STRESS

$$S_{st} = \frac{Mc}{I} = \frac{w l^2 r_o 4}{11.85\pi\,(r_o^4 - r_i^4)}$$

$$= \frac{\pi (r_o^2 - r_i^2)(r_o)(4)(35.5)^2}{11.85\pi\,(r_o^2 - r_i^2)(r_o^2 + r_i^2)}$$

$$= \frac{4 r_o (35.5)^2}{11.85\,(r_o^2 + r_i^2)}$$

$$S_{st} = 502 \text{ psi}$$

$$\mu = \frac{\text{DYNAMIC OBSERVED DEFLECTION}}{\text{STATIC CALCULATED DEFLECTION}}$$

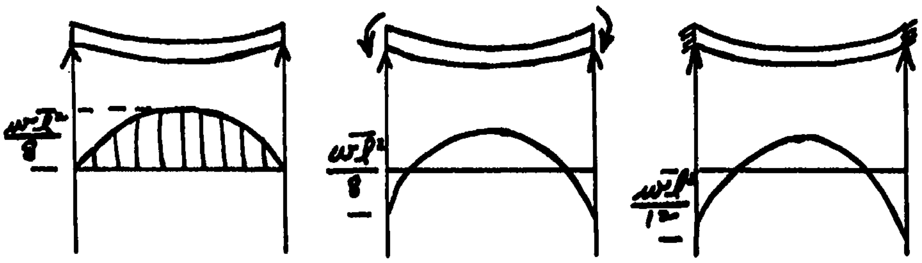
$$= \frac{0.025}{0.00038}$$

$$\mu = 65.8$$

STRESS AT CLAMP END

$S_A = \mu S_{sp} = (65.8)(502)$

$S_A = 33000$ PSI



$M = \frac{wl^2}{11.85}$

$\frac{wl^2}{8} = \frac{wl^2}{11.85} - \frac{wl^2}{N}$

$N = 24.7$

$M_c = \frac{wl^2}{24.7}$

$\phi = \frac{11.85}{24.7}$

$\phi = 0.48$

STRESS AT UNION

$S_{AC} = \mu \phi S_{sp} = (65.8)(0.48)(502)$

$S_{AC} = 15{,}850$ PSI (IF LINEAR)

DOUBLE AMPLITUDE – STRESS PROPORTIONALITY

$\frac{\Sigma da}{0.050} = \frac{(26000)(0.75)}{15850} = 1.224$

$\Sigma da = 0.0612$ INCH da

TABLE XXVIII. RESULTS OF INDETERMINATE BEAM CONFIGURATION VIBRATION TESTS.

SPEC. NO.	MATERIAL	FABRICATION	DESIRED DYNAMIC MIDSPAN STRESS	ACTUAL DYNAMIC MIDSPAN STRESS *	TEST TEMPERATURE	f_n (CPS)	REMARKS
19	347 STAINLESS STEEL	WELD UNION	19,500 PSI	9,070 PSI	200°F	160	2×10^6 CYCLES NO FAILURE
15	347 STAINLESS STEEL	BRAZE UNION	19,500 PSI	8,030 PSI	200°F	150	2×10^6 CYCLES NO FAILURE
28	AM350 STAINLESS STEEL	WELD UNION	33,000 PSI	18,600 PSI	600°F	163	2×10^6 CYCLES NO FAILURE
9	AM350 STAINLESS STEEL	BRAZE UNION	33,000 PSI	17,430 PSI	600°F	154	2×10^6 CYCLES NO FAILURE
W22	6061-T6 ALUMINUM	WELD UNION	12,000 PSI	62,500 PSI **	200°F	168	1.5×10^6 CYCLES FAILURE IN PARENT MATERIAL AT CLAMP END

* MATHEMATICAL ERRORS IN PRETEST CALCULATIONS RESULTED IN TESTING AT OTHER THAN THE DESIRED DYNAMIC STRESS.

** MATHEMATICAL ERRORS IN PRETEST CALCULATIONS RESULTED IN TESTING AT EXCESSIVELY HIGH STRESS LEVEL.

NOTE: ALL DATA FOR THESE TESTS ARE RECORDED IN ELS DATA BOOK NO. 2303 PGS. 138-173

DATA SUMMARY
SPECIMEN NO. 19

MATERIAL: 347 STAINLESS STEEL
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.083 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.286 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 29.0×10^6 PSI
TENSILE MODULUS (200°F): 27.9×10^6 PSI
TENSILE YIELD (200°F): 26,000 PSI
FABRICATION: WELDED

STATIC CALCULATED DEFLECTION

$\delta = 4.0 \times 10^{-4}$ INCH

NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

$f_{cc} = 156$ CPS

NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

$f_{ss} = 69.7$ CPS

EXPERIMENTALLY MEASURED NATURAL FREQUENCY

$f_e = 160$ CPS

$\varkappa = 0.95$

$M = \dfrac{wl^2}{11.85}$

ACTUAL DEFLECTION (1 "g" STATIC)

$\delta = 3.8 \times 10^{-4}$ INCH

$S_{sf} = 502$ PSI

$\mu = 65.8$

STRESS AT CLAMPED END

$S_A = 33000$ PSI

SPECIMEN NO. 19
Continued

$N = 24.7$

$M_c = \frac{wl^2}{24.7}$

$\phi = 0.48$

STRESS AT UNION

S_{RC} = 15,850 PSI (IF LINEAR)

DOUBLE AMPLITUDE — STRESS PROPORTIONALITY

Σda = 0.0612 INCHES da.

ENDURANCE – 2×10^6 CYCLES, NO FAILURE

ACTUAL TEST DOUBLE AMPLITUDE = 0.0353

∴ ACTUAL TEST STRESS = 9,070 PSI

DATA SUMMARY
SPECIMEN NO. 15

MATERIAL : 347 STAINLESS STEEL
LENGTH : 35.5 INCHES
WALL THICKNESS : 0.083 INCHES
OUTSIDE DIAMETER : 1.000 INCHES
MATERIAL DENSITY : 0.286 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 29.0×10^6 PSI
TENSILE MODULUS (200°F): 27.9×10^6 PSI
TENSILE YIELD (200°F): 26,000 PSI
FABRICATION: BRAZED UNION

STATIC CALCULATED DEFLECTION

$\delta = 4.0 \times 10^{-4}$ INCH

NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

f_{cc} = 156 CPS

NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

f_{ss} = 69.7 CPS

EXPERIMENTALLY MEASURED NATURAL FREQUENCY

f_e = 150 CPS

$\chi = 1.08$

$$M = \frac{w\ell^2}{12.25}$$

ACTUAL DEFLECTION (1 "g" STATIC)

$\delta = 4.32 \times 10^{-4}$

S_{SF} = 485 PSI

$\mu = 57.9$

STRESS AT CLAMPED END

S_A = 28,100 PSI

SPECIMEN NO. 15
(Continued)

$N = 23.05$

$M_c = \frac{wl^2}{23.05}$

$\phi = 0.531$

STRESS AT UNION

S_{A_c} = 14,900 PSI (IF LINEAR)

DOUBLE AMPLITUDE – STRESS PROPORTIONALITY

$2d_a$ = 0.0655 INCHES da.

ENDURANCE – 2×10^6 CYCLES, NO FAILURE

ACTUAL TEST DOUBLE AMPLITUDE = 0.0353

∴ ACTUAL TEST STRESS = 8,030 PSI

DATA SUMMARY
SPECIMEN NO. 28

MATERIAL : AM350 STAINLESS STEEL
LENGTH : 33.8 INCHES
WALL THICKNESS: 0.134 INCHES
OUTSIDE DIAMETER : 1.000 INCH
MATERIAL DENSITY : 0.282 LB/IN^3
TENSILE MODULUS (ROOM TEMP) : 28.6×10^6 PSI
TENSILE MODULUS (600°F) : 25.9×10^6 PSI
TENSILE YIELD (AS WELDED, 600°F) : 44,000 PSI
FABRICATION : WELDED

STATIC CALCULATED DEFLECTION

$\delta = 3.85 \times 10^{-4}$ INCH

NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

$f_{cc} = 159$ cps

NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

$f_{ss} = 71.1$ CPS

EXPERIMENTALLY MEASURED NATURAL FREQUENCY

$f_e = 163$ CPS

$\varkappa = 0.955$

$M = \dfrac{w\ell^2}{11.85}$

ACTUAL DEFLECTION (1 "g" STATIC)

$\delta = 3.68 \times 10^{-4}$ INCH

$S_{st} = 502$ PSI

$\mu = 68.0$

STRESS AT CLAMPED END

$S_A = 34,100$ PSI

SPECIMEN NO. 28
(Continued)

$N = 24.6$

$M_c = \frac{wl^2}{24.6}$

$\phi = 0.482$

STRESS AT UNION

S_{ac} = 16,450 PSI (IF LINEAR)

DOUBLE AMPLITUDE – STRESS PROPORTIONALITY

ξ_{da} = 0.10 INCHES da.

ENDURANCE – 2×10^6 CYCLES, NO FAILURE

ACTUAL TEST DOUBLE AMPLITUDE = 0.113 INCH

∴ ACTUAL TEST STRESS = 18,600 PSI

DATA SUMMARY
SPECIMEN NO. 9

MATERIAL: AM350 STAINLESS STEEL
LENGTH: 33.8 INCHES
WALL THICKNESS: 0.134 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.282 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 28.6 X 10^6 PSI
TENSILE MODULUS (600°F): 25.9 X 10^6 PSI
TENSILE YIELD (AS WELDED, 600°F): 44,000 PSI
FABRICATION: BRAZED UNION

STATIC CALCULATED DEFLECTION

$\delta = 3.85 \times 10^{-4}$ INCH

NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

$f_{cc} = 159$ CPS

NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

$f_{ss} = 71.1$ CPS

EXPERIMENTALLY MEASURED NATURAL FREQUENCY

$f_e = 154$ CPS

$\varkappa = 1.065$

$$M = \frac{wl^2}{12.2}$$

ACTUAL DEFLECTION (1 "g" STATIC)

$\delta = 4.1 \times 10^{-4}$ INCH

$S_{st} = 487.5$ PSI

$\mu = 61.0$

STRESS AT CLAMPED END

$S_A = 29,700$ PSI

SPECIMEN NO. 9
(Continued)

$N = 23.2$

$M_0 = \frac{wl^2}{23.2}$

$\phi = 0.526$

STRESS AT UNION

S_{AC} = 15,650 PSI (IF LINEAR)

DOUBLE AMPLITUDE - STRESS PROPORTIONALITY

$\not{L}$ da = 0.105 INCHES da.

ENDURANCE - 2×10^6 CYCLES, NO FAILURE

ACTUAL TEST DOUBLE AMPLITUDE = 0.117 INCH

$\therefore$ ACTUAL TEST STRESS = 17,430 PSI

DATA SUMMARY
SPECIMEN No. W22

MATERIAL: 6061-T6 ALUMINUM
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.058 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.098 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 9.9×10^6 PSI
TENSILE MODULUS (200°F): 9.7×10^6 PSI
TENSILE YIELD (AS WELDED, 200°F): 16,000 PSI
FABRICATION: WELDED

STATIC CALCULATED DEFLECTION

$\delta = 3.76 \times 10^{-4}$ INCH

NATURAL FREQUENCY OF CLAMPED-CLAMPED BEAM

$f_{cc} = 163$ CPS

NATURAL FREQUENCY OF SIMPLY SUPPORTED BEAM

$f_{ss} = 72.8$ CPS

EXPERIMENTALLY MEASURED NATURAL FREQUENCY

$f_e = 168$ CPS

$\chi = 0.9375$

$$M = \frac{w l^2}{11.8}$$

ACTUAL DEFLECTION (1 "g" STATIC)

$\delta = 3.52 \times 10^{-4}$ INCH

$S_{st} = 480$ PSI

$\mu = 71$

STRESS AT CLAMPED END

$S_A = 34,100$ PSI

SPECIMEN W22
(Continued)

$N = 24.85$

$M_c = \frac{w l^2}{24.85}$

$\phi = 0.475$

STRESS AT UNION

$S_{AC} = 16,175$ (IF LINEAR)

DOUBLE AMPLITUDE - STRESS PROPORTIONALITY

$2 d_a = 0.0371$ INCHES d_a.

ENDURANCE — 1.5×10^6 CYCLES, FAILURE IN PARENT MATERIAL AT CLAMPED END.

ACTUAL TEST DOUBLE AMPLITUDE = 0.143

$\therefore$ ACTUAL TEST STRESS = 62,500 PSI

SIMPLE SUPPORT BEAM CONFIGURATION VIBRATION TESTS

THEORETICAL DEVELOPMENT

ASSUMPTIONS

1. THAT THE TEST FIXTURING RESULTS IN A BEAM CONFIGURATION APPROXIMATING A SIMPLE SUPPORT, BUT LYING INTERMEDIATE BETWEEN A SIMPLY SUPPORTED BEAM AND AN INDETERMINATE BEAM.

2. THAT THE TEST ITEM BE THE UNION OR WELDMENT AND NOT THE TUBING MATERIAL.

3. THAT UNIONS OR WELDED AREAS NOT BE CONSIDERED IN CALCULATIONS.

4. THAT NOTCH CONCENTRATIONS DUE TO CHANGE IN DIAMETRICAL DISTANCE FROM TUBING MATERIAL TO UNION MATERIAL OR FROM TUBING MATERIAL TO WELD MATERIAL NOT BE CONSIDERED IN CALCULATIONS.

DEFINITION OF TERMS

f_n = FUNDAMENTAL RESONANT FREQUENCY, CPS

g = 386 INCHES/SEC^2

δ_s = STATIC DEFLECTION, INCHES

δ_d = DYNAMIC DEFLECTION, INCHES

δ_o = REQUIRED INPUT DEFLECTION AT f_n, INCHES

n = DEGREE OF END CONSTRAINT

w = WEIGHT PER UNIT LENGTH, LB/IN

l = LENGTH, INCHES

E = TENSION MODULUS OF ELASTICITY, PSI

I = CROSS-SECTIONAL MOMENT OF INERTIA, INCHES^4

K = CONSTANT FOR SITUATION, INCHES

t = WALL THICKNESS, INCHES

d_o = OUTSIDE DIAMETER, INCHES

D = MATERIAL DENSITY, LB/INCH^3

F_{Y} = TENSILE YIELD STRENGTH, PSI

A = CROSS-SECTIONAL AREA, INCHES^2

M_E = END MOMENT, LB-IN

M_M = MIDSPAN MOMENT, LB-IN

S_{MS} = STATIC MIDSPAN STRESS, PSI

S_{MD} = DYNAMIC MIDSPAN STRESS, PSI

S_R = REQUIRED MIDSPAN STRESS, PSI

G = REQUIRED INPUT ACCELERATION AT f_n

THEORY

(1) $$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_s}}$$, CPS

THE DEFLECTION δ_s IS VARIABLE IN ACCORDANCE WITH MATERIAL AND CONDITIONS AS FOLLOWS:

(2) $$\delta_s = \frac{n w l^4}{384 EI}$$, INCH

(3) $$\delta_s = n K$$, INCH

$$K = \frac{w l^4}{384 EI}$$, INCH

$$K = \frac{D A l^4}{384 E A \frac{1}{16}\left[d_o^2 + (d_o - 2t)^2\right]}$$

BUT, $I = \frac{A}{16}\left[d_o^2 + (d_o - 2t)^2\right]$

(4) $K = \frac{D\ell^4}{24E\left[d_o^2 + (d_o - 2t)^2\right]}$, INCH

NOW COMBINING EQUATIONS (1) AND (2)

(5) $f_n = \frac{1}{2\pi}\sqrt{\frac{g}{n K}}$, CPS

TO DETERMINE THE END MOMENT WE HAVE

$$n K = 5K - \frac{2 M_E \ell^2}{16 E I}$$

$$= 5K - \frac{2 K M_E 24}{w \ell^2}$$

OR,

(6) $M_E = \frac{(5-n)\, w \ell^2}{48}$ LB-IN

AND TO OBTAIN THE MIDSPAN MOMENT

$$M_M = \frac{w\ell^2}{8} - M_E$$

$$M_M = \frac{w\ell^2}{8}\left[1 - \frac{5-n}{6}\right]$$

(7) $M_M = \frac{w\ell^2}{48}\left[1 + n\right]$, LB-IN

SINCE $S = \frac{Mc}{I}$

THE MIDSPAN STRESS (STATIC) IS

$$S_{MS} = \frac{M_M c}{I}$$

$$S_{MS} = \frac{DA\ell^2[1+\varkappa]\frac{d_o}{2}}{48A\frac{t}{16}[d_o^2+(d_o-2t)^2]}$$

(8) $$S_{MS} = K\frac{4Ed_o(1+\varkappa)}{\ell^2} \quad \text{, PSI}$$

THE STRESS PER UNIT DYNAMIC GRAVITATIONAL ACCELERATION WILL BE DETERMINED USING THE OBSERVED DEFLECTION AT THE FUNDAMENTAL RESONANT FREQUENCY DUE TO A ± 1 g ACCELERATION INPUT AND THE CALCULATED STATIC DEFLECTION AS FOLLOWS:

$$S_{MD} = \frac{\delta_g}{\delta_s} S_{MS}$$

(9) $$S_{MD} = \frac{\delta_g}{\varkappa K} S_{MS} \quad \text{, PSI/g}$$

SINCE THE REQUIRED STRESS LEVEL IS 75 PERCENT OF THE TENSILE YIELD STRENGTH (S_E), THE REQUIRED INPUT ACCELERATION FORCE WILL BE

$$G = \frac{S_E}{S_{MD}} \quad \text{, } \pm g$$

AND THE INPUT DYNAMIC DEFLECTION AT THE MIDSPAN WILL BE

$$\delta_D = \delta_g G \quad \text{, INCH}$$

PROCEDURE OUTLINE

1. DETERMINE K:

   CALCULATE $K = \dfrac{D\ell^4}{24E[d_o^2 + (d_o - 2t)^2]}$, INCH

2. STABILIZE TEST SPECIMEN AT REQUIRED TESTING TEMPERATURE.

3. DETERMINE THE FOLLOWING PARAMETERS FOR A $\pm 1\,g$ ACCELERATION INPUT:

   (a) FUNDAMENTAL RESONANT FREQUENCY

   (b) PEAK TO PEAK DISPLACEMENT AT MIDSPAN

   (c) THE Q READING AND GAIN SETTING FROM OSCILLOSCOPE

4. DETERMINE END CONSTRAINT CONSTANT:

   CALCULATE $\varkappa = \dfrac{1}{K}\left(\dfrac{3.13}{f_\varkappa}\right)^2$

5. DETERMINE MIDSPAN STATIC STRESS:

   CALCULATE $S_{MS} = K\,\dfrac{4Ed_o(1+\varkappa)}{\ell^2}$, PSI

6. DETERMINING MIDSPAN DYNAMIC STRESS:

   CALCULATE $S_{MD} = \dfrac{\delta_g}{\varkappa K}\,S_{MS}$, PSI/g

7. CALCULATE TEST G LEVEL:

   $G = \dfrac{S_E}{S_{MD}}$, $\pm g$

PROCEDURE OUTLINE
(Continued)

8. CALCULATE TEST DEFLECTION LEVEL:

$$\delta_D = \delta_g G \quad , \text{INCH}$$

9. VERIFY ARRANGEMENT WITH STRAIN GAGE READING.

10. COMPARISON SHOWN IN FIGURE 79.

TYPICAL EXAMPLE
(347 Stainless Steel - Spec No. 16)

MATERIAL - 347 STAINLESS STEEL
FABRICATION - BRAZED UNION
WALL THICKNESS - 0.083 INCHES
OUTSIDE DIAMETER - 1.000 INCHES
MATERIAL DENSITY - 0.286 LB/IN³
TENSION MODULUS AT ROOM TEMP - 29.0 X10⁶ PSI
TENSION MODULUS AT 200°F - 27.9 X10⁶ PSI
TENSION YIELD AT 200°F - 26,000 PSI

NEGLECT UNION.

1) $$K = \frac{D\ell^4}{24E[d_o^2 + (d_o - 2t)^2]}$$

$$K = \frac{(0.286)(35.5)^4}{(24)(27.9 \times 10^6)[1 + (0.834)^2]}$$

$$\underline{K = 4.0 \times 10^{-4} \text{ INCH}}$$

3) (a) FUNDAMENTAL RESONANT FREQUENCY $\underline{f_n = 77 \text{ CPS}}$

(b) MIDSPAN PEAK TO PEAK DISPLACEMENT $\underline{2\delta_g = 0.075 \text{ INCH}}$

(c) Q = 3.8 DIVISIONS AT STRAIN GAIN 200

4) $$n = \frac{1}{K}\left(\frac{3.13}{f_n}\right)^2$$

$$n = \frac{1}{4.0 \times 10^{-4}}(16.55 \times 10^{-4})$$

$$\underline{n = 4.13}$$

TYPICAL EXAMPLE
(Continued)

5) $$S_{MS} = K \frac{4 E d_o (1+x)}{\ell^2}$$

$$S_{MS} = \frac{(4.0 \times 10^{-4})(4)(27.9 \times 10^6)(1)(5.13)}{(35.5)^2}$$

$$\underline{S_{MS} = 182 \text{ PSI}}$$

6) $$S_{MD} = \frac{\delta_g}{x K} S_{MS}$$

$$S_{MD} = \frac{(0.0375)(182)}{(4.13)(4.0 \times 10^{-4})}$$

$$\underline{S_{MD} = 4,130 \text{ PSI}}$$

7) $$G = \frac{S_E}{S_{MD}}$$

$$G = \frac{(26000)(0.75)}{(4130)}$$

$$\underline{G = \pm 4.72 \text{ g}}$$

8) $$\delta_d = \delta_g G$$

$$\delta_d = (0.0375)(4.72)$$

$$\underline{\delta_d = 0.177 \text{ INCH}} \text{ (SINGLE AMPLITUDE)}$$

TABLE XXIX. RESULTS OF SIMPLE SUPPORT BEAM CONFIGURATION VIBRATION TESTS.

Specimen Number	Material	Fabrication	Dynamic Mid-Span Stress	Test Temperature	f_x	Remarks
16	347 Stainless	Brazed Union	19,500 PSI	200°F	76	269,000 Cycles Failure occurred under edge of union
21S	347 Stainless	Welded	19,500 PSI	200°F	80	2,000,000 Cycles No Failure
30	AM350	Welded	33,000 PSI	600°F	75	2,000,000 Cycles No Failure
11	AM 350	Brazed Union	33,000 PSI	600°F	72	2,000,000 Cycles No Failure
21A	6061-T6	Welded Union	12,000 PSI *	200°F	77	137,500 Cycles Failure in heat affected zone of weld

* This specimen had previously been subjected to 2,000,000 cycles at 2400 PSI stress.

Note. All data for these tests are recorded in ELS Data Book No: 2303: Pgs 138-173

DATA SUMMARY
SPECIMEN 21A

MATERIAL: 6061-T6
FABRICATION: WELDED
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.058 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.098 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 9.9×10^6 PSI
TENSILE MODULUS (200°F): 9.7×10^6 PSI
TENSILE YIELD (AS WELDED, 200°F): 16000 PSI

$K = 3.77 \times 10^{-4}$ INCH
$f_n = 77$ CPS
$2\delta_g = 0.0225$ INCH
$Q = 4.3$ DIVISIONS AT STRAIN GAIN 50
$\varkappa = 4.38$
$S_{MS} = 62.4$ PSI
$S_{MD} = 425$ PSI/g
$G = \pm 28.2$ g
$\delta_d = 0.3175$ INCH

ENDURANCE: 137,500 CYCLES – FAILURE IN HEAT AFFECTED ZONE OF WELD.

DATA SUMMARY
SPECIMEN NO. 16

MATERIAL: 347 STAINLESS STEEL
FABRICATION: BRAZED UNION
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.083 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.286 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 29.0×10^6 PSI
TENSILE MODULUS (200°F): 27.9×10^6 PSI
TENSILE YIELD (200°F): 26,000 PSI

$K = 4.0 \times 10^{-4}$ INCH
$f_n = 77$ CPS
$2\delta_g = 0.075$ INCH
$Q_g = 3.8$ DIVISIONS AT STRAIN GAIN 200
$x = 4.13$
$S_{NS} = 182$ PSI
$S_{MD} = 4{,}130$ PSI/g
$G = \pm 4.72$ g
$\delta_d = 0.177$ INCH

ENDURANCE: 269,000 CYCLES - FAILURE OCCURRED UNDER EDGE OF UNION

DATA SUMMARY
SPECIMEN 21 S

MATERIAL: 347 STAINLESS STEEL
FABRICATION: WELDED
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.083 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.286 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 29.0×10^6 PSI
TENSILE MODULUS (200°F): 27.9×10^6 PSI
TENSILE YIELD (200°F): 26,000 PSI

$K = 4.0 \times 10^{-4}$ INCH
$f_n = 80$ CPS
$2\delta_g = 0.090$ INCH
Q = 3.8 DIVISIONS AT STRAIN GAIN 200
$\varkappa = 3.83$
$S_{NS} = 171$ PSI
$S_{ND} = 5{,}025$ PSI/g
$G = \pm 3.88\,g$
$\delta_d = 0.175$ INCHES

ENDURANCE: 2×10^6 CYCLES – NO FAILURE

DATA SUMMARY
SPECIMEN NO. 30

MATERIAL: AM350 COND. SCT
FABRICATION: WELDED
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.134 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.282 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 28.7×10^6 PSI
TENSILE MODULUS (600°F): 25.9×10^6 PSI
TENSILE YIELD (600°F): 44,000 PSI

$K_o = 4.69 \times 10^{-4}$ INCH
$f_n = 75$ CPS
$2\delta_q = 0.070$ INCHES
$Q^q = 1.0$ DIVISIONS AT STRAIN GAIN 200
$x = 3.71$
$S_{MS} = 181.5$ psi
$S_{MD} = 3650$ psi/g
$G = \pm 9.05$ g
$\delta_D = 0.3165$ INCHES

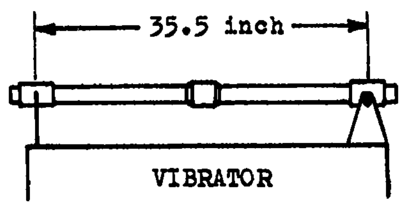
ENDURANCE: 2×10^6 CYCLES – NO FAILURE

DATA SUMMARY
SPECIMEN NO. 11

MATERIAL: AM 350 COND. SCT
FABRICATION: BRAZED UNION
LENGTH: 35.5 INCHES
WALL THICKNESS: 0.134 INCHES
OUTSIDE DIAMETER: 1.000 INCHES
MATERIAL DENSITY: 0.282 LB/IN^3
TENSILE MODULUS (ROOM TEMP): 28.7×10^6 PSI
TENSILE MODULUS (600°F): 25.9×10^6 PSI
TENSILE YIELD (600°F): 44,000 PSI

$K_o = 4.69 \times 10^{-4}$ INCH
$f_n = 72$ CPS
$2\delta_y = 0.065$ INCHES
$Q = 2.5$ DIVISIONS AT STRAIN GAIN 100
$\eta = 4.03$
$S_{MS} = 194$ PSI
$S_{MD} = 3360$ PSI/g
$G = \pm 9.82$ g
$\delta_o = 0.319$ INCHES

ENDURANCE: 2×10^6 CYCLES – NO FAILURE



Tube: AM 350
OD: 1.0 inch
Wall: 0.134 inch
Fitting Sleeve Length: 1½ inch
Specimen Length: 35.5 inches
Material Density: 0.282 lb/in^3
E = 28.7 x 10^6 psi
Resonant Frequency for
Configuration Shown: 77 cps
Input Acceleration: ± 2 g

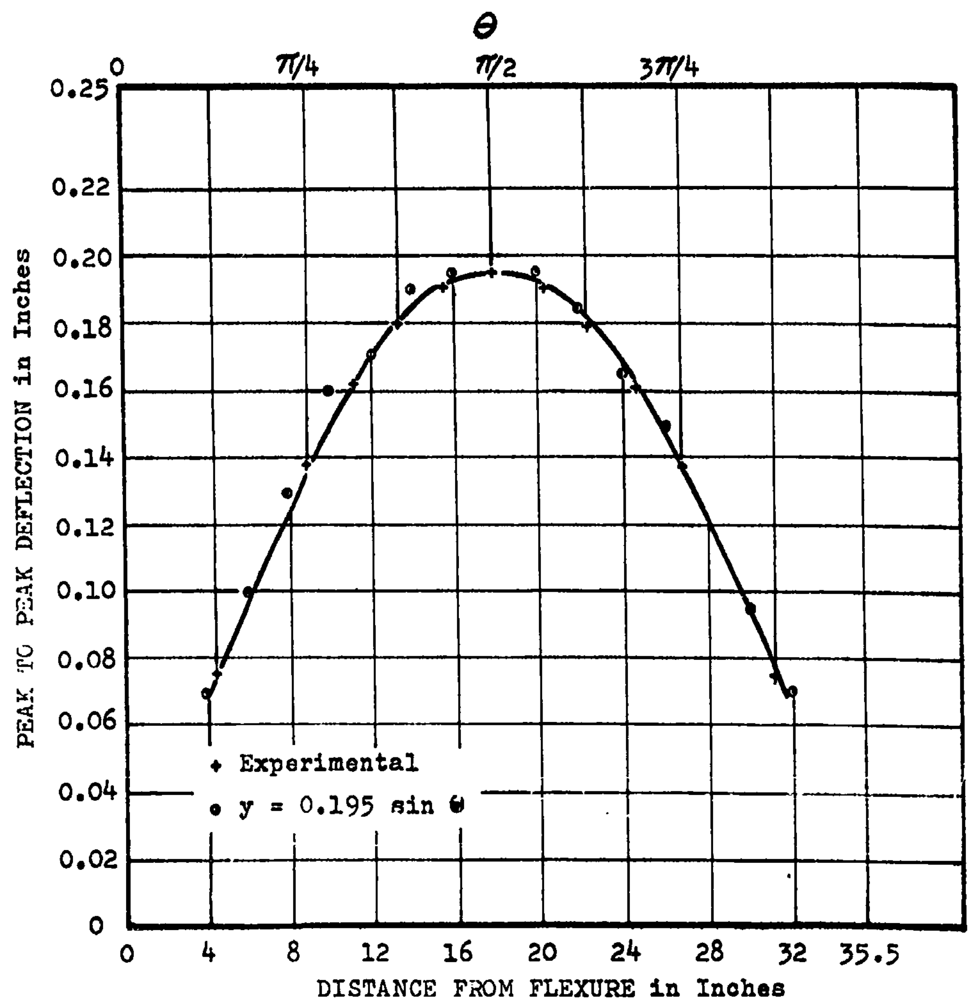


FIGURE 79. COMPARISON OF CALCULATED AND ACTUAL BENDING SHAPE OF A TUBE SET UP IN A SIMPLE SUPPORT BEAM CONFIGURATION AND VIBRATED AT FUNDAMENTAL RESONANCE.

APPENDIX IV

STRESS CORROSION TESTING

STRESS CORROSION TESTING WITH AN
ELASTICALLY FLEXED SIMPLE BEAM SPECIMEN

GENERAL

The NAA/LAD Research Laboratory has conducted stress corrosion tests for a number of years using an elastically flexed simple beam type test specimen. This specimen is normally used for testing sheet material, although the specimen can be machined from bar stock.

The test specimen is usually one inch wide, eight inches long, and the thickness can vary from 0.010 inch to 0.125 inch. The sample calculations and graphs which are included here were prepared for this specimen size; however, there are a number of suitable sizes which can be selected and similar graphs can be prepared for use with such specimens.

After the specimens are machined to the proper dimensions and inspected, they should be carefully cleaned and passivated, or treated, in a manner prescribed for the material when it is to be used with the test fluid in service.

Tensile control tests should be conducted on coupons of the test material processed in the same fashion and at the same time as the stress corrosion test specimens. The tensile tests are to determine the ultimate and yield strengths, the elongation (ductility), and the modulus of elasticity of the test material.

Stress corrosion tests should be conducted using more than one specimen of the material for any given testing condition. Three or four specimens for each test condition are recommended, considering the variability in results that is frequently obtained in such tests. The specimens are loaded in flexure to the desired stress level. Test stress levels may be representative of service loadings, or they may be arbitrarily selected to cover a range of possible service conditions, such as 40, 60, 80 and perhaps even 90 percent of the tensile yield strength of the test material.

The specimens are constrained at the ends only, between blocks which are in turn held by a bolt and a nut. Appropriate deflections as determined from the graphs or by calculation are imposed on each specimen over a chord distance of four inches (for the eight inch long specimen). The test fixture parts can be made of the same material as the specimen being tested in order to eliminate any bi-metallic reactions, or they can be made of some other material and the specimen ends and test fixture coated with a protective or preservative coating to prevent their corroding or other reaction with the test fluid.

TESTING

The following recommendations are presented in regard to the conduct of stress corrosion tests using the specimen design suggested in this Appendix.

Testing should be carried out in containers made from the same material as that of the specimen being tested. The test specimen can be supported by brackets or a simple shelf, also made of the same material as the test specimen. In this way any electrolytic action or concentration of foreign ions which would interfere with the test can be avoided. The specimen support should be such that the maximum free surface of the specimen is exposed to the action of the test solution.

Test solutions should be agitated during the testing in order to more effectively simulate service conditions. In order to prevent leakage of the test solution or contamination from sealing devices, stirring can be accomplished by encapsulating a small magnet in the same material as the test specimen and container, and mounting the assembly to a magnetic stirring device.

A completely clean surface free from fingerprints and other soils is essential for proper testing. The specimen should be cleaned by a thorough procedure. Ultrasonic cleaning will provide an exceptionally clean surface. After cleaning, the specimen should be passivated or otherwise treated in the same manner as the components of a system for handling the test fluid would be prior to service. During the cleaning and passivation and assembly into the test container, the specimens should be handled with clean tongs or with the hands covered with clean white gloves.

It is suggested that two specimens be exposed in each of the test fluids. One specimen should be fully immersed in the liquid phase. The other specimen should be in the vapor phase.

The test specimens should be measured and weighed prior to exposure to the test solutions. After exposure, the specimens should be carefully examined both macroscopically and microscopically for the extent of corrosive attack. The total weight loss should also be determined, with care being taken to distinguish between specimen weight and the weight of any deposits which may adhere to the surface of the specimen.

The test solutions may be analyzed for one or more of the major constituent elements in the test specimen material, both before and again after the test exposure. By this means any changes in ion concentration can be determined which may provide a measure of the rate of attack of the solution on the test specimen.

SPECIMEN DESIGN

Referring to Figure 80, let GHJK be a section of an elastically deformed beam of thickness HK. Then let:

- c = the length of the chord JLK
- h = the height of the circular segment described by arc JK and chord JLK
- R_o = the radius of curvature at the outer fiber of the stressed beam
- R_n = the radius of curvature at the neutral axis (center) of the stressed beam
- B = the angle subtended by the arc JK
- S_o = the length of the arc JK, i.e., the length of the beam section at the outer fiber
- S_n = the length of the beam section at the neutral axis.

Then:

$$R_o^2 = \left(\frac{c}{2}\right)^2 + (R_o - h)^2$$

$$R_o^2 = \frac{c^2}{4} + R_o^2 - 2R_o h + h^2$$

$$2R_o h = \frac{c^2}{4} + h^2$$

$$R_o = \frac{c^2 + 4h^2}{8h}$$

Also:

$$\sin\left(\frac{B}{2}\right) = \frac{c/2}{R_o} = \frac{c}{2R_o}$$

$$B = 2\sin^{-1}\frac{c}{2R_o}$$

For given values of "c" and "h", "R_o" can be calculated. From this information the angle "B" can be determined and replaced by its equivalent value in radians. The arc lengths "S_o+ and "S_n" are found from:

$$S_o = R_o B$$

$$S_n = R_n B \quad (\text{where } R_n = R_o - ½HK)$$

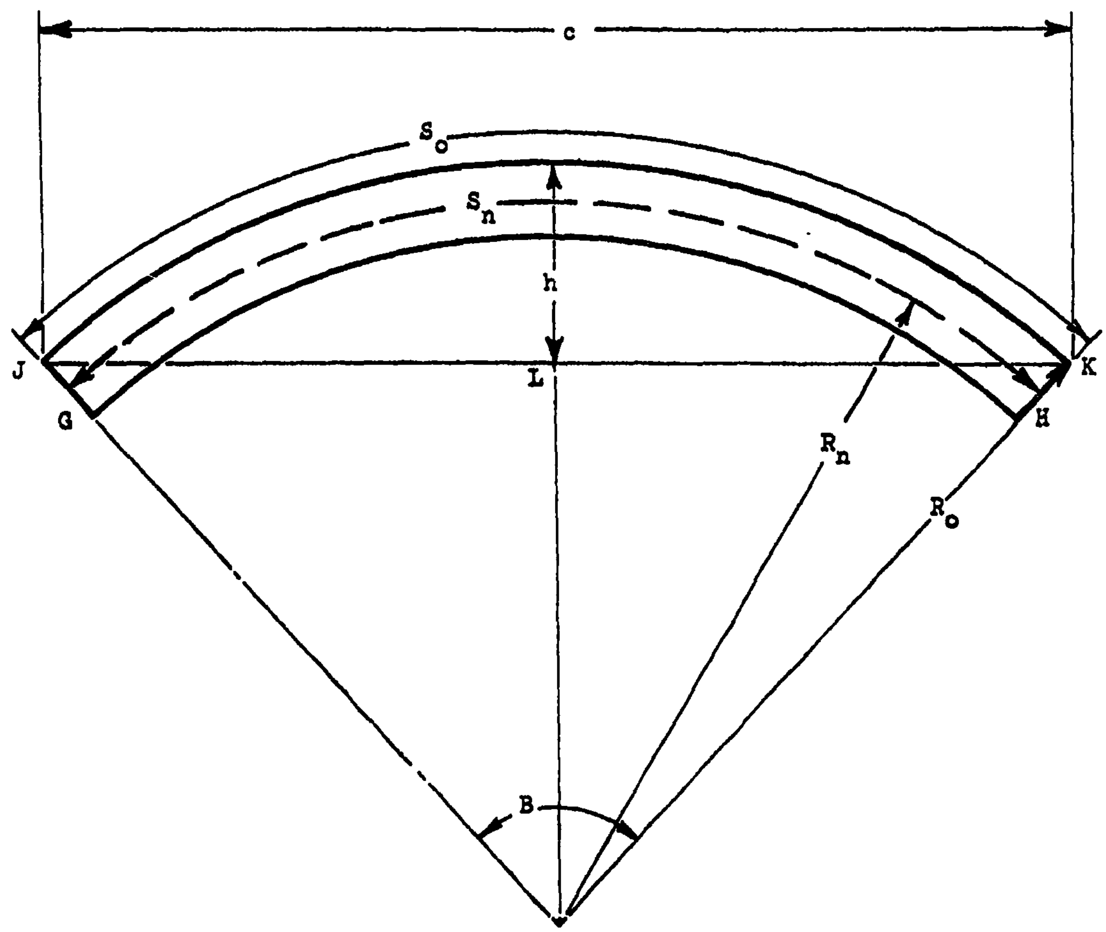


Figure 80. Schematic Side View Of A Section
Of An Elastically Flexed Beam.

Finally:

$$\text{elastic strain} \quad e = \frac{S_o - S_n}{S_n}$$

from which the fiber stress is derived according to:

$F_t = Ee$ where F_t is the tensile stress and

E = modulus of elasticity in tension for the material.

As an example: let c = 4.00 inches (held constant)
and h = 0.2 inch.
Then, material 0.050 inch thick would have a radius of curvature eual to:

$$R_o = \frac{c^2 + 4h^2}{8h} = \frac{(4.00)^2 + (4)(0.2)^2}{(8)(0.2)}$$

R_o = 10.100 inches (R_n = 10.075 inches for 0.050 inch thich material)

$$B = 2\sin^{-1}\frac{c}{2R_o} = 2\sin^{-1}\frac{4.00}{(2)(10.10)}$$

B = 22.842082 degrees, or

B = 0.3986695 radians

From the above,

$$S_o = R_oB$$

$$S_o = (10.10)(0.3986695)$$

S_o = 4.0265617 inches,

Similarly,

$$S_n = R_nB$$

$$S_n = (10.075)(0.3986695)$$

S_n = 4.0165950 inches

$$e = \frac{S_o - S_n}{S_n}$$

$$e = \frac{4.0265617 - 4.0165950}{4.0165950}$$

e = 0.0024814 inches/inch

Fiber stress is then:

$$F_t = Ee \quad \text{and assuming } E = 29{,}000{,}000 \text{ psi},$$

$$F_t = (29.0 \times 10^6)(0.0024814)$$

$$F_t = 71{,}960 \text{ psi}$$

Using similar calculations, the accompanying graphs were produced from which the stress-deflection relationships are determined for the test specimens, Figures 81, 82 and 83.

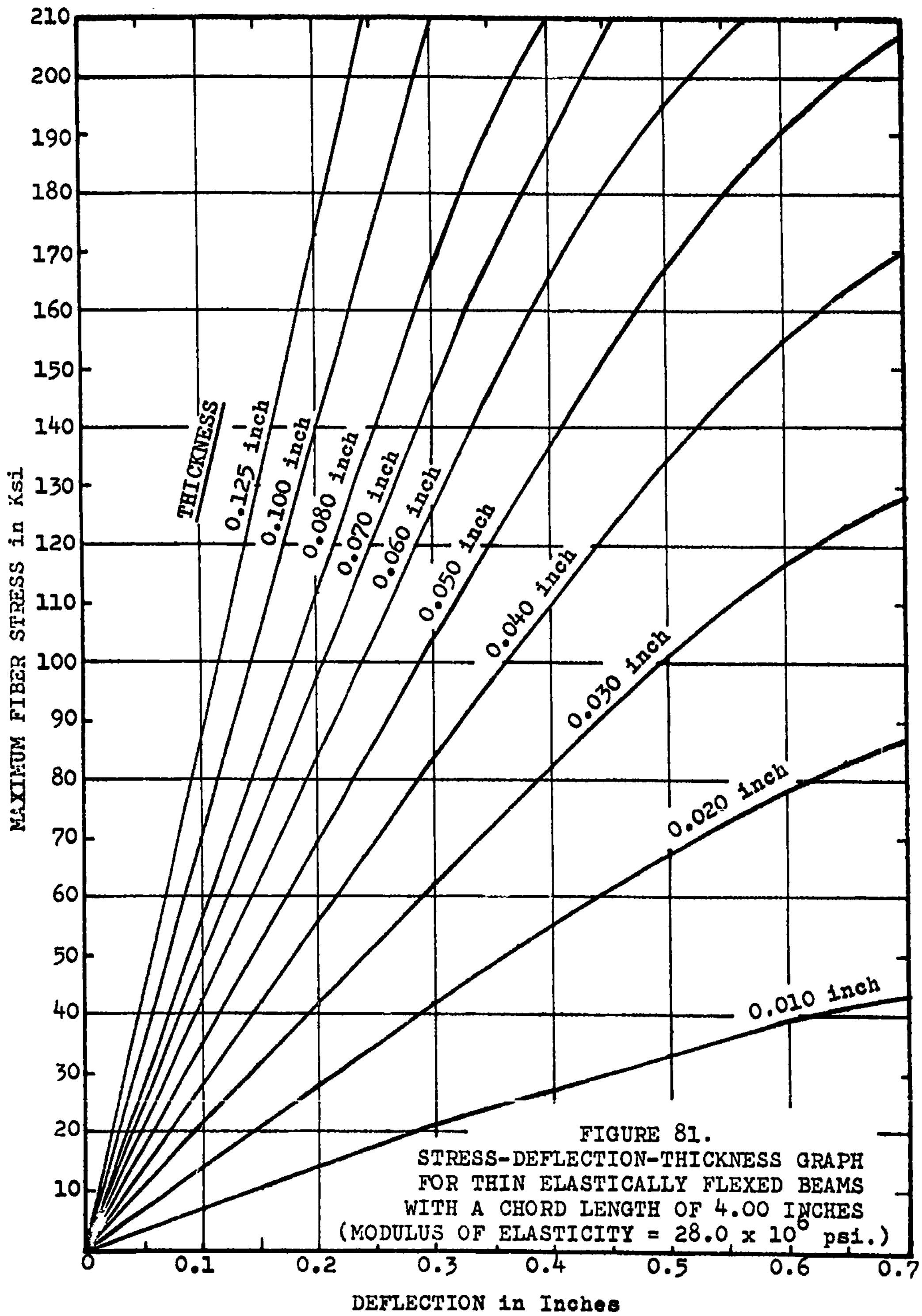


FIGURE 81.
STRESS-DEFLECTION-THICKNESS GRAPH FOR THIN ELASTICALLY FLEXED BEAMS WITH A CHORD LENGTH OF 4.00 INCHES (MODULUS OF ELASTICITY = 28.0×10^6 psi.)

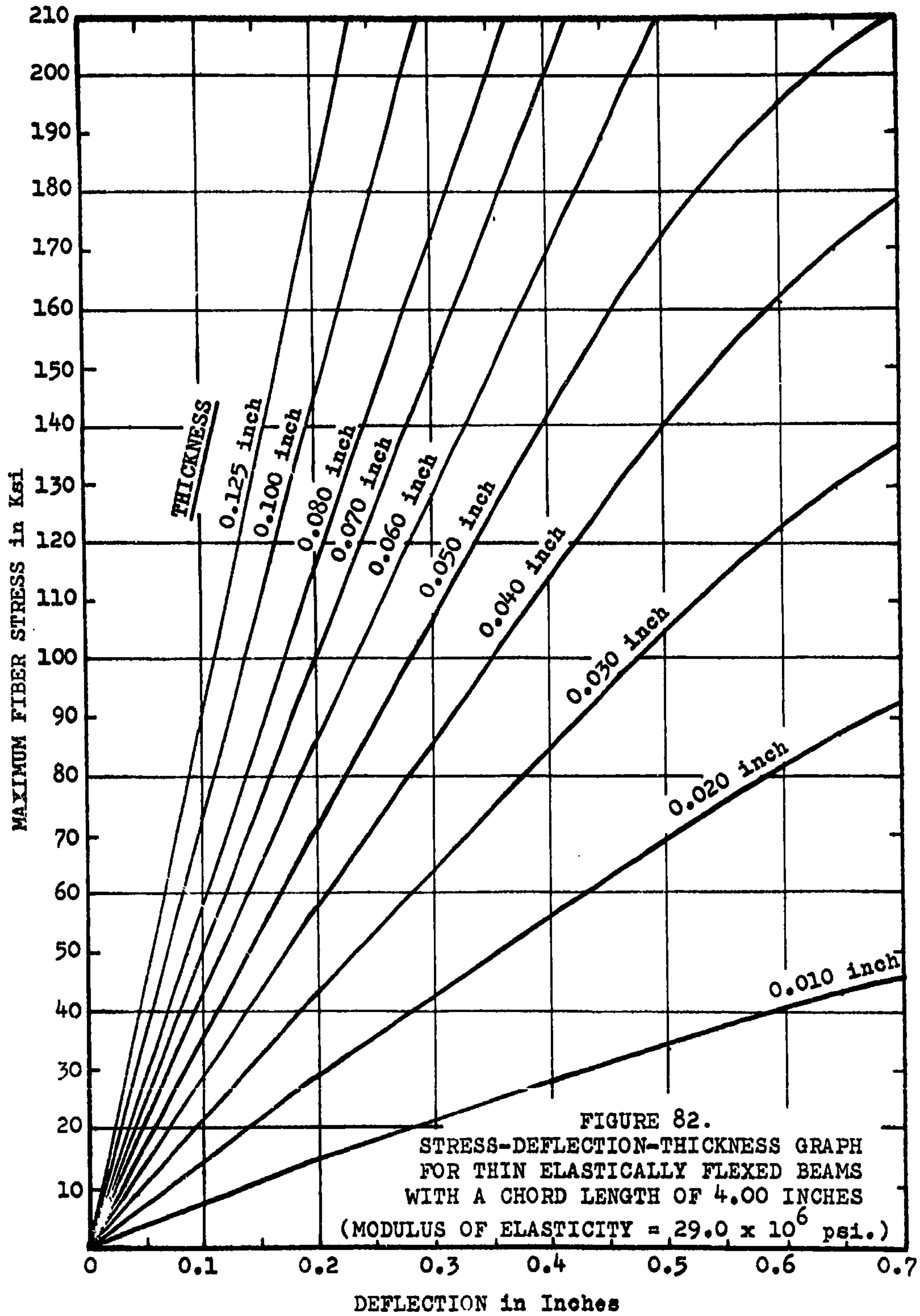


FIGURE 82.
STRESS-DEFLECTION-THICKNESS GRAPH FOR THIN ELASTICALLY FLEXED BEAMS WITH A CHORD LENGTH OF 4.00 INCHES
(MODULUS OF ELASTICITY = 29.0×10^6 psi.)

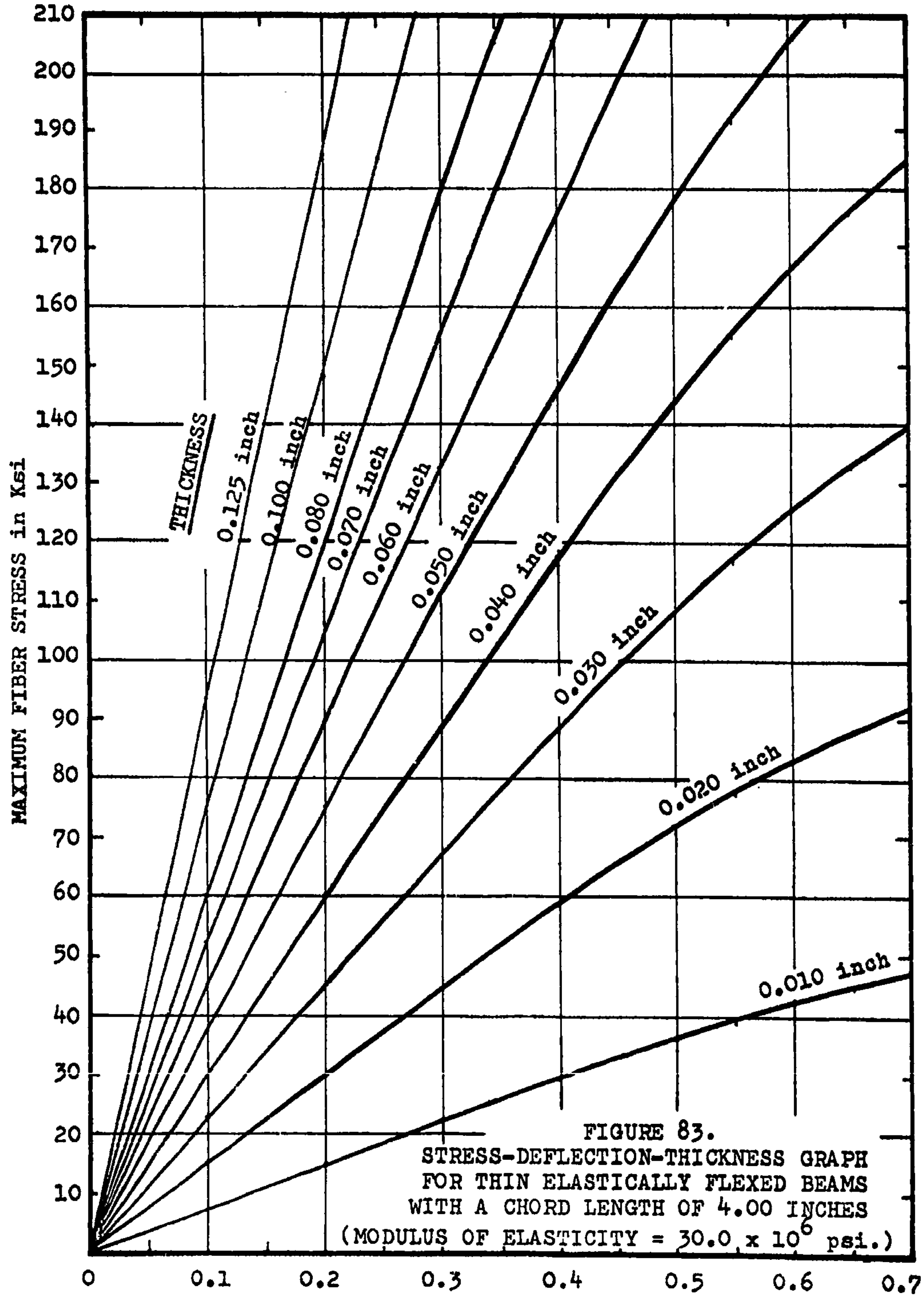


FIGURE 83.
STRESS-DEFLECTION-THICKNESS GRAPH FOR THIN ELASTICALLY FLEXED BEAMS WITH A CHORD LENGTH OF 4.00 INCHES (MODULUS OF ELASTICITY = 30.0 x 10^6 psi.)

APPENDIX V

TUBE WELDING SPECIFICATION

SPECIFICATION FOR

AUTOMATIC TIG WELDING OF TUBING JOINTS

1. SCOPE

1.1 This specification establishes the weld tooling and procedural requirements for production of welded tubular joints in the specific tubing materials and sizes shown in Table I.

1.2 This specification applies only to the shielded arc automatic tungsten-inert gas welding (TIG) process. In this process the electric arc is initiated and maintained between a tungsten electrode and the work piece in an inert gas envelope. This specification is concerned with direct current straight polarity applications in which the tungsten electrode is the cathode and the workpiece is the anode.

2. APPLICABLE MATERIALS

2.1 Tubing Materials

MIL-T-8808	Tubing, Steel, Corrosion-Resistant (18-8 Stabilized), Aircraft Hydraulic Quality (ASG), Comp 347, Type I or II
AMS 5554	Tubing, Seamless — 16.5Cr, 4.5Ni, 2.9Mo, 0.1N (AM 350)
Commercial	Tubing, Alloy, Corrosion and Heat Resistant, Nickel Base, Rene' 41 (AMS 5712 may be referenced for material from which tubing is made)
MIL-T-7081	Tubing, Aluminum Alloy, Seamless, Round, 6061, Aircraft Quality (ASG)

2.2 Filler Wire

QQ-R-566	Rods, Welding, Aluminum and Aluminum Alloys, Type I, Class FS-RA143 (4043 Alloy)

2.3 Shielding Gas

MIL-A-18455	Argon, Technical
Commercial	Helium, Technical Grade A

TABLE I. APPLICABLE TUBING MATERIALS AND SIZES.

TUBING MATERIAL	TUBING DIMENSIONS	
	OD (Inches)	WALL THICKNESS (Inches)
AISI 321 Stainless Steel	1/8 3	0.010 0.070
AISI 347 Stainless Steel	1 3	0.083 0.250
AM 350 Stainless Steel	1/4 1	0.042 0.134
Rene' 41 Alloy	1/8 3/4	0.010 0.030
6061 Aluminum Alloy	1	0.058

3. WELDING EQUIPMENT REQUIREMENTS

3.1 Welding Tools. Two types of weld tooling are required for joining the tubing materials listed in Table I. The primary difference in the design of the two types of tooling is the method of adding filler material to the weld joint. One type of tool provides filler material in the form of wire which is supplied through a wire feed attachment. The second type of tool has no provision for filler material addition, the filler material being provided by use of a preplaced sleeve, where required. Both types of welding tools are operated by a ring and pinion gear which are driven by a flexible cable from a variable speed DC electric motor. A tungsten welding electrode is mounted in the ring gear and traveld around the circumference of the tube as the gear is rotated.

3.1.1 When the joint is assembled with a fitted sleeve, which provides filler material for the weld and also aligns the tube ends, the only weld tooling required is the rotating tungsten electrode and the inlet for the inert shieldding gas. A design drawing of this type of unit is shown in Figure 1.

3.1.2 The joints which are assembled without the use of a sleeve require additional provision for aligning the tube ends, such as tack welding, and may also require the addition of filler material in the form of wire. The tool described in paragraph 3.1.1 must be modified to provide for the filler wire to be added to the weld puddle at a controlled rate for joining aluminum alloy tubing and thick-walled tubing of other materials. A drawing of a prototype tool designed for weld joining one-inch diameter tubing with addition of filler wire is shown in Figure 2, and the detail parts for this tool are shown in Figure 3.

3.2 Remote Control Unit

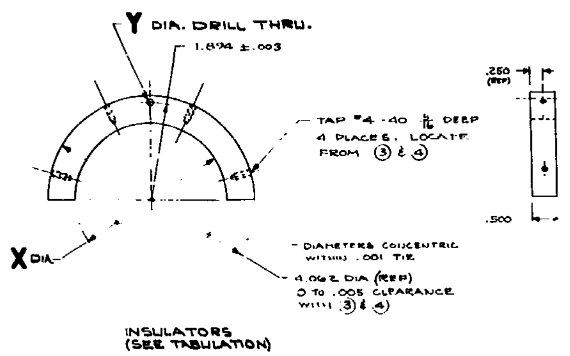
3.2.1 A remote control unit which can be used to control the following weld variables is required:

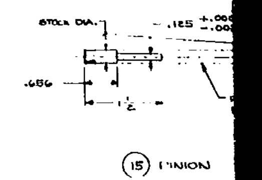
(a) Welding current (2 to 200 amperes)
(b) Welding voltage (0 to 50 volts indicating meter only)
(c) Travel speed (0 to 10 inches per minute)
(d) Wire feed entry speed (0 to 20 inches per minute)
(e) Inert gas shield control (on-off)
(f) Power control (on-off)

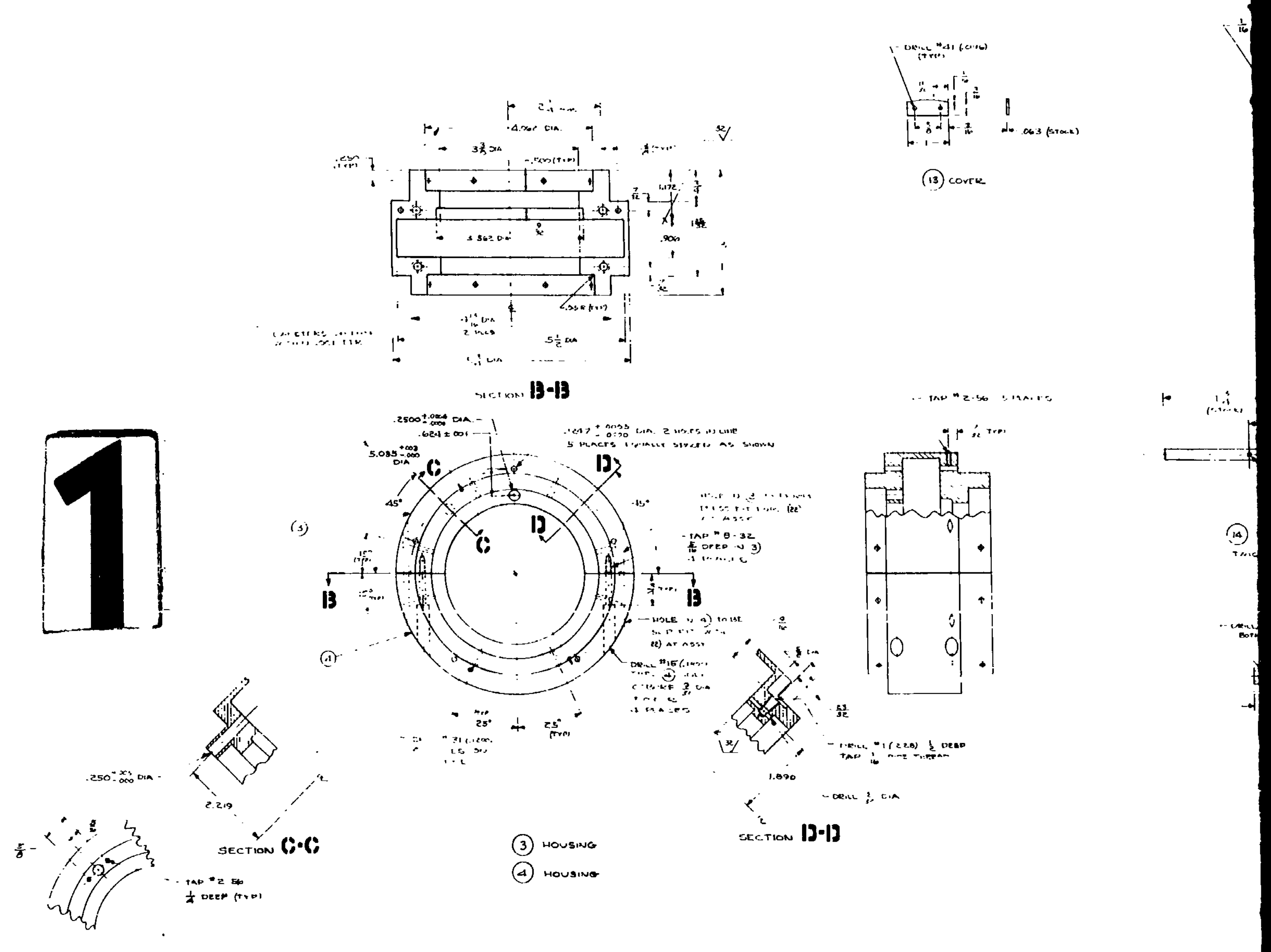
3.2.2 A design drawing of a typical remote control unit is shown in Figure 4. This unit would require incorporation of a variable resistor for wire feed control.

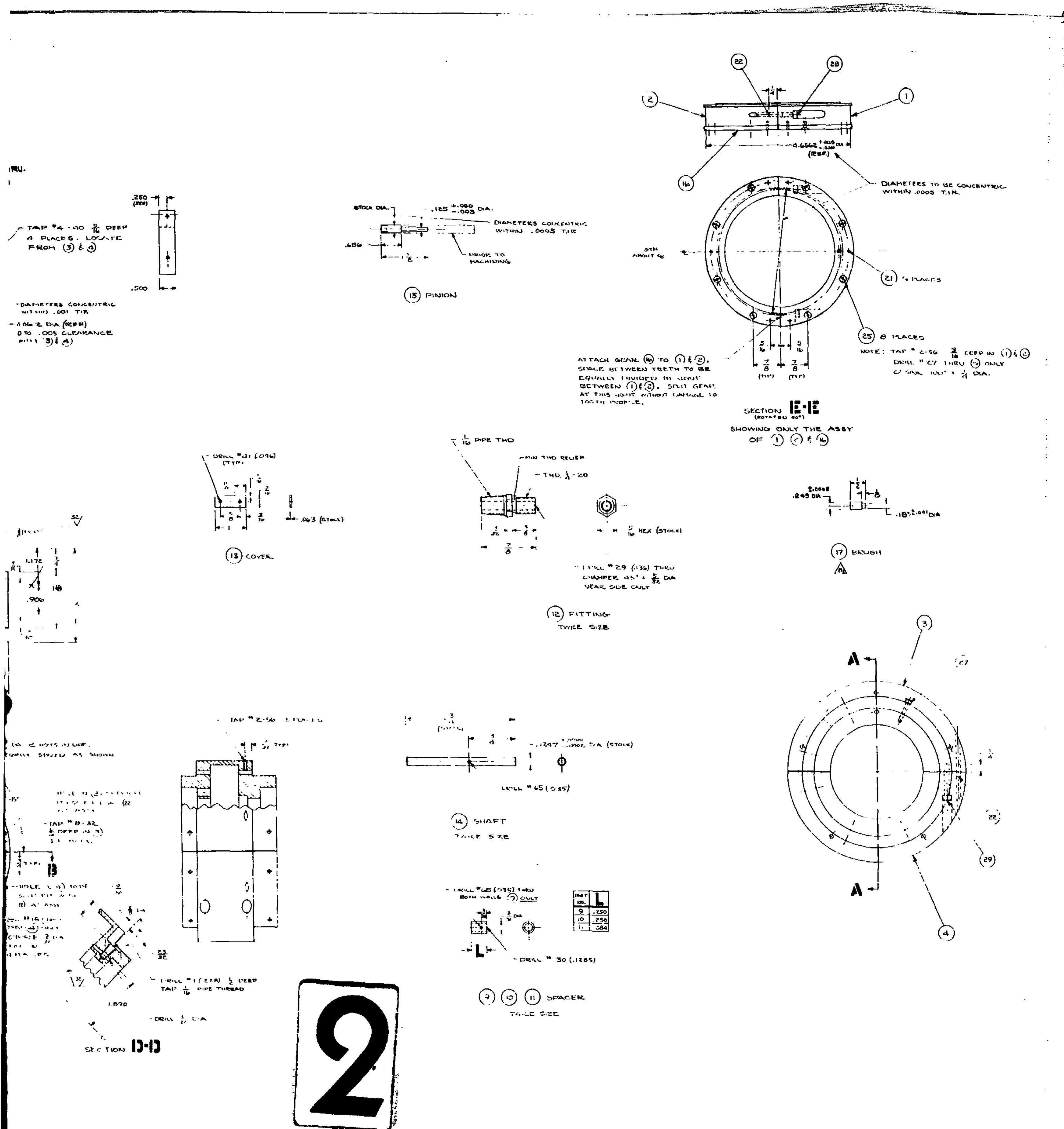
3.3 Power Supply. And standard TIG welding direct-current power supply may be used. A maximum output of 200 amperes DC will be sufficient for joining the tubing materials covered by this specification. High frequency current superimposed on the welding current is required to facilitate arc initiation.

PT NO	X	Y
5	3.010 [illegible]	9/64
6	3.010 [illegible]	—
7	2.007 [illegible]	9/64
8	2.007 [illegible]	—
31	.129 [illegible]	9/64
32	.129 [illegible]	—
33	.254 [illegible]	9/64
34	.254 [illegible]	—
35	.379 [illegible]	9/64
36	.379 [illegible]	—
37	.504 [illegible]	9/64
38	.504 [illegible]	—
39	.630 [illegible]	9/64
40	.630 [illegible]	—
41	.755 [illegible]	9/64
42	.755 [illegible]	—
43	.880 [illegible]	9/64
44	.880 [illegible]	—
45	1.005 [illegible]	9/64
46	1.005 [illegible]	—
47	1.255 [illegible]	9/64
48	1.255 [illegible]	—
49	1.505 [illegible]	9/64
50	1.505 [illegible]	—
51	1.756 [illegible]	9/64
52	1.756 [illegible]	—
53	2.257 [illegible]	9/64
54	2.257 [illegible]	—
55	2.507 [illegible]	9/64
56	2.507 [illegible]	—
57	2.760 [illegible]	9/64
58	2.760 [illegible]	—



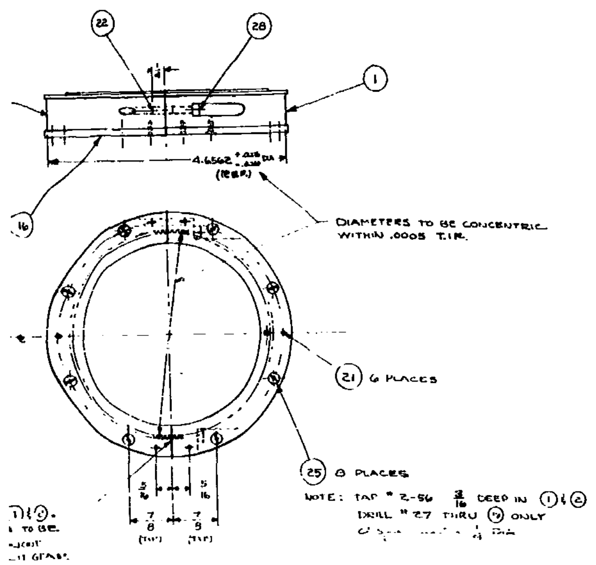




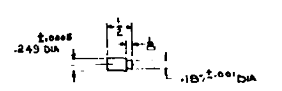


PART NO.	L
9	.250
10	.250
11	.384

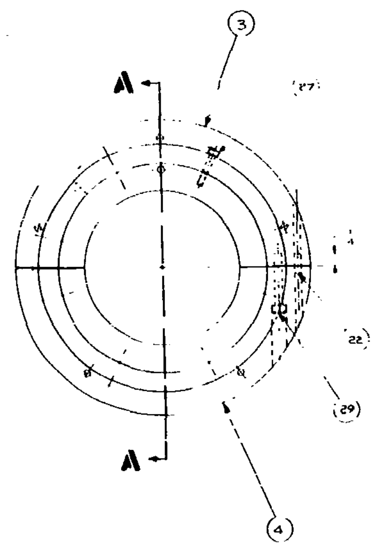
2

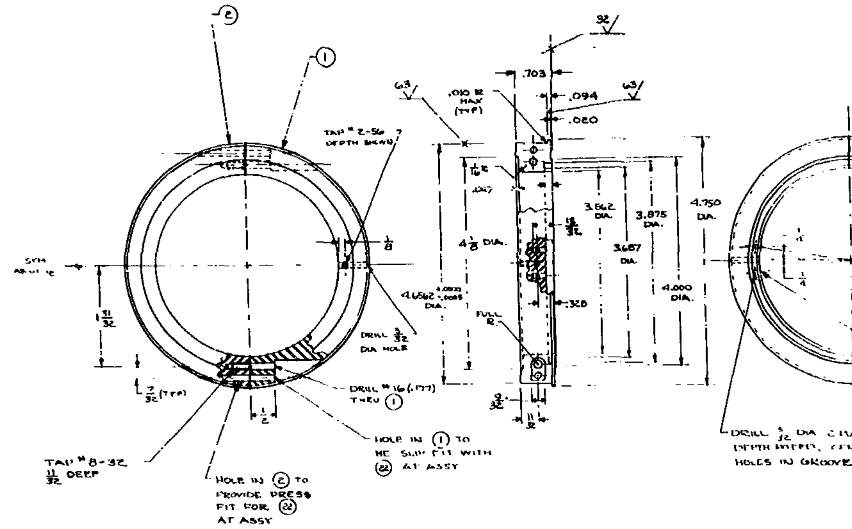


SECTION E-E
(ROTATED 90°)
SHOWING ONLY THE ASSY
OF (1) (2) & (16)

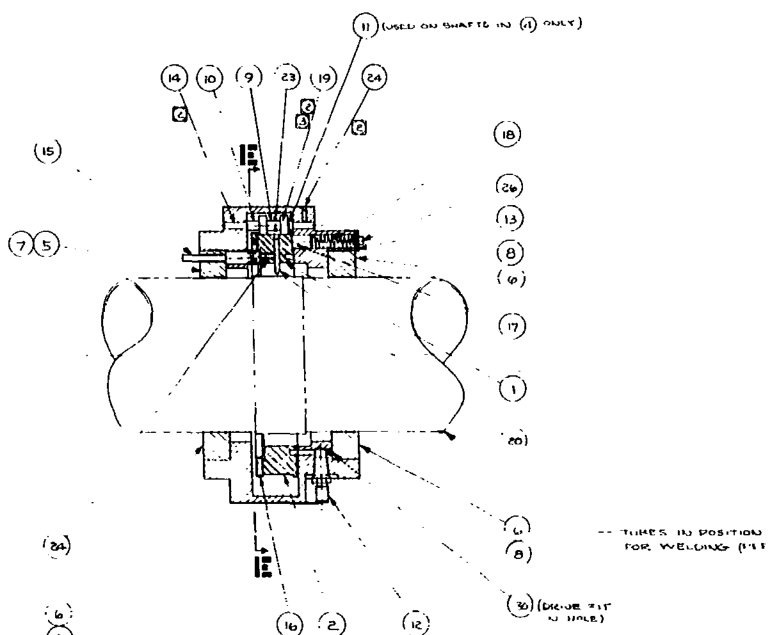


(17) BUSH



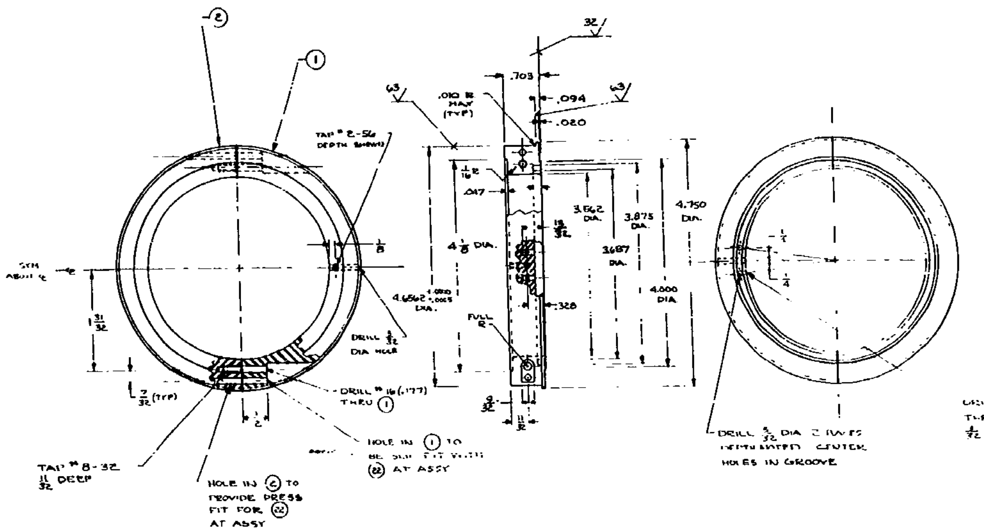


(1) HOLDER
(2) HOLDER



SECTION A-A
(SOME PARTS ROTATED INTO PLANE OF PAPER)

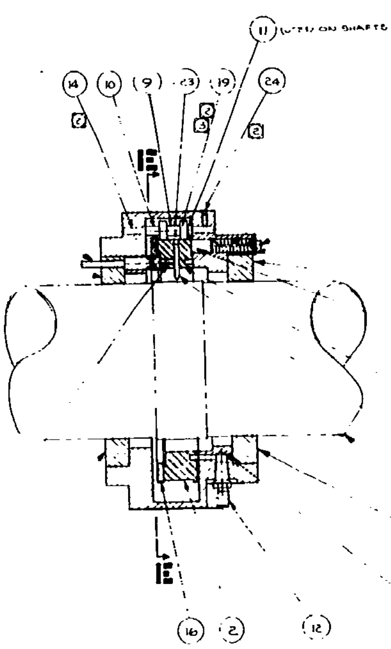
3



DRILL $\frac{1}{16}$ DIA HOLE THRU WALL INTO THE $\frac{3}{32}$ DIA HOLE 2 PLACES

(1) HOLDER

(2) HOLDER



SECTION A-A

(SOME PARTS ROTATED INTO PLANE OF PAPER)

4

4 BEARINGS RUN DRY, CLEAN OUT ALL LUBRICANT

3 WITH THE ASSEMBLY OF (1) & (2) HOLDERS AGAINST (2) & (3) HOUSINGS, MOVE (8) SHAFT UNTIL [illegible] (9) JUST CONTACTS THE SHOULDER. TIGHTEN SET SCREW (24). HOLDERS SHOULD TURN FREELY AFTER ADJUSTMENT. TWO PLACES

NOTES: UNLESS OTHERWISE NOTED

(2) DASH NUMBERS FOR RIVET DIA, LENGTH, OR GRIP ARE OBTAINED FROM RIVET DRAWINGS	(1) BASIC CODE LETTERS
(3) MANUFACTURED RIVET HEADS ARE UNDERSTOOD TO BE ON THE NEAR SIDE OF THE DRAWING, UNLESS AN "F" IS SHOWN IN THE NORTHEAST QUADRANT OF THE CODE. SHEETS ARE NUMBERED AWAY FROM THE MANUFACTURED HEAD, SHEET ONE BEING ADJACENT TO THE HEAD.	[illegible]
(4) FLUSH RIVETING OPERATIONS	[illegible]

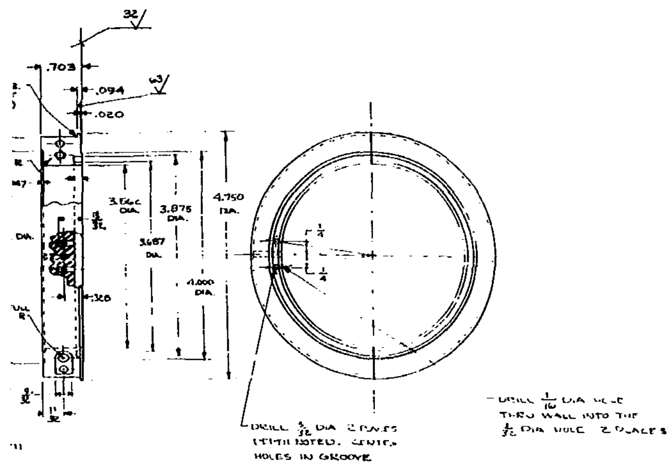


FIGURE 1.

) HOLDER
) HOLDER

WELDING (TYP)

5

REQD	REQD	PART NUMBER	DESC	MATERIAL	
2		58	INSULATOR	LAMINATED SILICONE SHT.	1/2 x 2 [illegible]
1		57	INSULATOR		
3		56	INSULATOR		
1		55	INSULATOR		
2		54	INSULATOR		
1		53	INSULATOR		
3		52	INSULATOR		
1		51	INSULATOR		
3		50	INSULATOR		
1		49	INSULATOR		
3		48	INSULATOR		
1		47	INSULATOR		
2		46	INSULATOR		
1		45	INSULATOR		
1		44	INSULATOR		
1		43	INSULATOR		
3		42	INSULATOR		
1		41	INSULATOR		
1		40	INSULATOR		
1		39	INSULATOR		
1		38	INSULATOR		
1		37	INSULATOR		
2		36	INSULATOR		
1		35	INSULATOR		
2		34	INSULATOR		
1		33	INSULATOR		
1		32	INSULATOR		
1		31	INSULATOR	LAMINATED SILICONE SHT.	1/2 x 2 [illegible]
1		30	PLUG	BRASS BAR	[illegible] DIA
4		29	SCREW	SOC HD CAP	#8-32
2		28	SCREW		#8-32
16		27	SCREW		#4-40
2		26	SCREW	SOC HD CAP	#2-56
8		25	SCREW	FLAT HD [illegible]	#2-56
6		24	SET SCREW		#2-56
5		23	COTTER PIN		1/16 DIA
4		22	DOWEL		1/8 DIA
6		21	DOWEL		1/16 DIA
1		20	ELECTRODE	[illegible]	3/16 DIA
10		19	BALL BEARING	[illegible]	AA1
[illegible]		18	SPRING	[illegible]	[illegible]
[illegible]		17	BRUSH	COMM. GRAPHITE ROD	1/8 DIA x
1		16	[illegible] GEAR	BOSTON GEAR	Y14
1		15	PINION	PERFECT GEAR & MFG.	AB8
5		14	SHAFT	PERFECT GEAR & MFG.	24-
1		13	COVER	BRASS SH	[illegible]
1		12	FITTING	BRASS HEX BAR	[illegible]
2		11	SPACER	303 CRES BAR	3/16 DIA
5		10	SPACER	[illegible] CRES BAR	3/16 DIA
5		9	SPACER	303 CRES BAR	[illegible]
3		8	INSULATOR	LAMINATED [illegible] SH	1/2 x 2 [illegible]
1		7	INSULATOR		
3		6	INSULATOR		
1		5	INSULATOR	LAMINATED [illegible]	1/2 x 2 [illegible]
1		4	HOUSING	[illegible]	[illegible]
1		3	HOUSING	[illegible]	[illegible]
1		2	HOLDER	303 CRES BAR	4 3/4 D[illegible]
1		1	HOLDER	303 CRES BAR	4 3/4 D[illegible]

LIST OF MATERIAL

4 REAPPLY [illegible] DRY [illegible] CLEAN OUT ALL LUBRICANT [illegible] WITH THE ASSEMBLY [illegible] SHAFT [illegible] CONTACTS THE SHOULDER [illegible] SET SCREW (24). [illegible] AFTER ADJUSTMENT [illegible]

NOTES: UNLESS OTHERWISE NOTED

FASTENER CODING

CONVENTIONAL AND BLIND RIVETS SHALL BE INSTALLED PER NAA SPECIFICATION FA3-1

HI-SHEAR RIVETS, BOLTS, NUTS, SCREWS AND STUDS SHALL BE INSTALLED PER NAA SPECIFICATION FA3-6

DRILLED HOLE TOLERANCES

TOLERANCES EXCEPT AS NOTED: ANGLES ±1/2° FRACTIONS ±1/32 DECIMALS ±.010

SURFACE ROUGHNESS PER MIL-STD-10

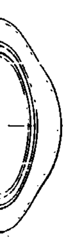
HEAT TREAT

FINISH

DATE | DR BY | CK BY | APPD BY | APPD BY

REVISIONS		
SYM	DESCRIPTION	DATE APPROVAL
A	1. ADDED PT. 31–58 INCL.	R AYOTTE 2-4-63
B	1. DELETED NOTES 1, 2 & 5 2. REVISED PT. 17 (PIST. & MAT'L) 3. REVISED PT. 18 (ADDED MAT'L)	R AYOTTE 3-19-64

6



— DRILL 1/16 DIA HOLE THRU WALL INTO THE 1/2 DIA HOLE 2 PLACES

FIGURE 1.

REQD	ZONE	PART NUMBER	DESC	MATERIAL	SIZE	ZONE	MAT'L SPEC	LINE
3		58	INSULATOR	LAMINATED SILICONE SHT	1/2 x 2 3/8 x 4 5/16		MIL-P-997 TYPE GSG	058
1		57	INSULATOR					057
3		56	INSULATOR					056
1		55	INSULATOR					055
2		54	INSULATOR					054
1		53	INSULATOR					053
3		52	INSULATOR					052
1		51	INSULATOR					051
3		50	INSULATOR					050
1		49	INSULATOR					049
2		48	INSULATOR					048
1		47	INSULATOR					047
2		46	INSULATOR					046
1		45	INSULATOR					045
2		44	INSULATOR					044
1		43	INSULATOR					043
3		42	INSULATOR					042
1		41	INSULATOR					041
2		40	INSULATOR					040
1		39	INSULATOR					039
2		38	INSULATOR					038
1		37	INSULATOR					037
2		36	INSULATOR					036
1		35	INSULATOR					035
2		34	INSULATOR					034
1		33	INSULATOR					033
2		32	INSULATOR					032
1		31	INSULATOR	LAMINATED SILICONE SHT	1/2 x 2 3/8 x 4 5/16		MIL-P-997 TYPE GSG	031
1		30	PLUG	BRASS BAR	1/2 DIA x 1/8			030
4		29	SCREW	SOC HD CAP	#8-32 x 1			029
2		28	SCREW		#8-32 x 3/4			028
16		27	SCREW		#4-40 x 1/2			027
2		26	SCREW	SOC HD CAP	#2-56 x 1/4			026
8		25	SCREW	FLAT HD 100°	#2-56 x 1/4			025
6		24	SET SCREW		#2-56 x 1/8			024
5		23	COTTER PIN		1/32 DIA x 1/4			023
4		22	DOWEL		1/8 DIA x 3/8			022
6		21	DOWEL		1/16 DIA x 1/4			021
1		20	ELECTRODE	[illegible]	1/2 DIA x 3/4			020
16		19	BALL BEARING	[illegible]	AAI-3S			019
1		18	SPRING	[illegible]	[illegible]			018
1		17	BRUSH	COMM. GRAPHITE ROD	1/4 DIA x 1/2			017
1		16	INTERNAL GEAR	BOSTON GEAR	YI 48107			016
1		15	PINION	[illegible]	ARR-1			015
5		14	SHAFT	[illegible] GEAR	24-B6			014
1		13	COVER	BRASS SH	[illegible]			013
1		12	FITTING	BRASS HEX BAR	[illegible] x 3/8			012
2		11	SPACER	303 CRES BAR	[illegible]			011
8		10	SPACER	303 CRES BAR	3/16 DIA x 1/4			010
5		9	SPACER	303 CRES BAR	[illegible] x 1/4			009
3		8	INSULATOR	LAMINATED SILICONE SH	1/2 x 2 3/8 x 4 5/16		MIL-P-997 TYPE GSG	008
1		7	INSULATOR					007
3		6	INSULATOR					006
1		5	INSULATOR	LAMINATED SILICONE SH	1/2 x 2 3/8 x 4 5/16		MIL-P-997 TYPE GSG	005
1		4	HOUSING	[illegible]	5 DIA x 7			004
1		3	HOUSING	[illegible]	5 1/2 DIA x 3			003
1		2	HOLDER	303 CRES BAR	4 3/4 DIA x 1/4			002
1		1	HOLDER	303 CRES BAR	4 3/4 DIA x 1/4			001

LIST OF MATERIAL

X-4537

X-4537

4 [illegible] WITH THE ASSEMBLY [illegible] SHAFT [illegible] CONTACTS THE SHOULDER. TIGHTEN SET SCREW [illegible] SHOULD [illegible] AFTER ADJUSTMENT [illegible]

NOTES: UNLESS OTHERWISE NOTED

FASTENER CODING

DRILLED HOLE TOLERANCES

TOLERANCES EXCEPT AS NOTED: ANGLES ±1/2°, FRACTIONS ±1/32, DECIMALS ±.010

SURFACE ROUGHNESS PER MIL-STD-10 (FAA-219)

HEAT TREAT

FINISH

DATE 5-15-62

DR BY PETERSON

CHK BY

APPD BY

APPD BY

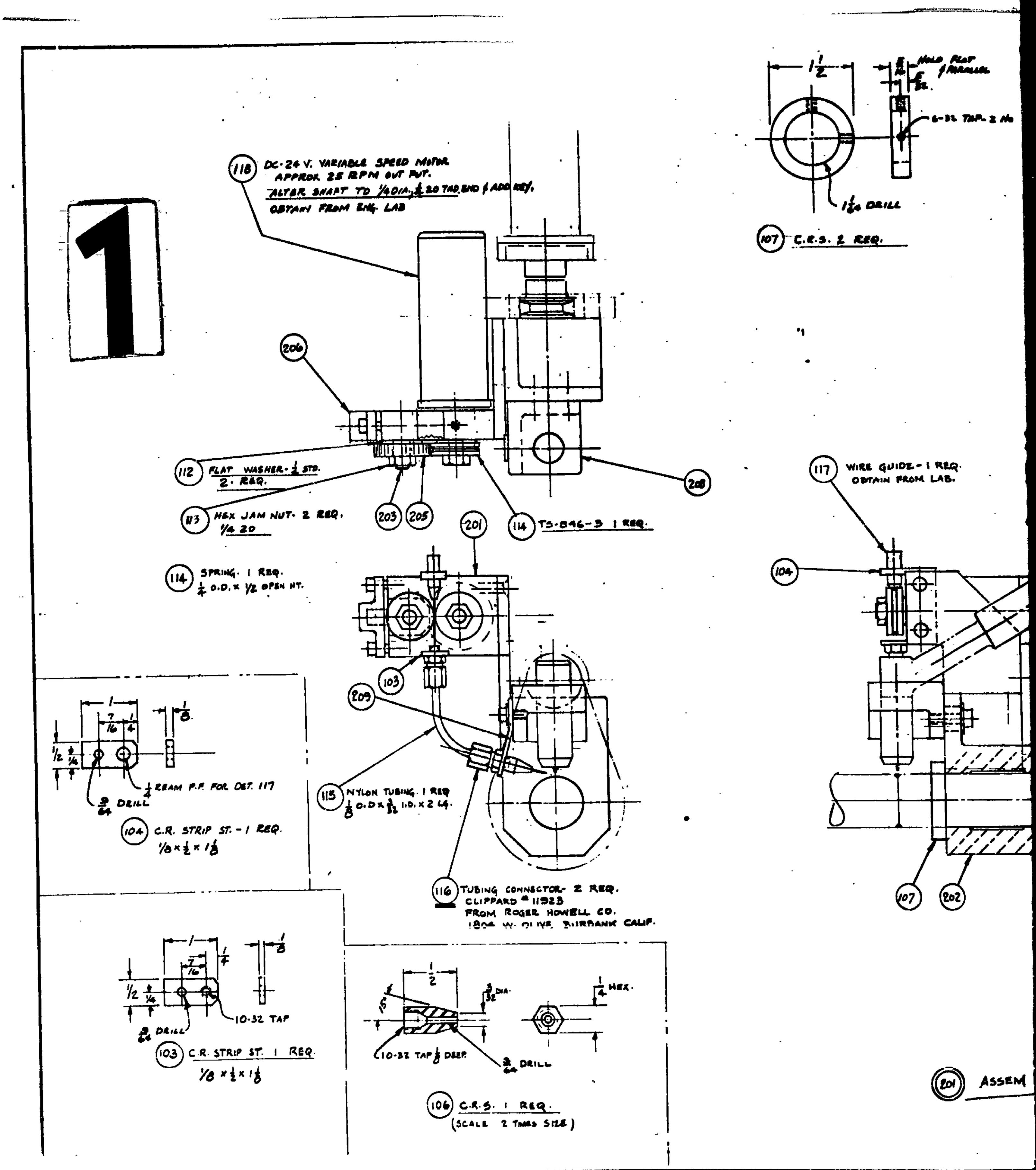
12-307

TUBE BUTT WELDER

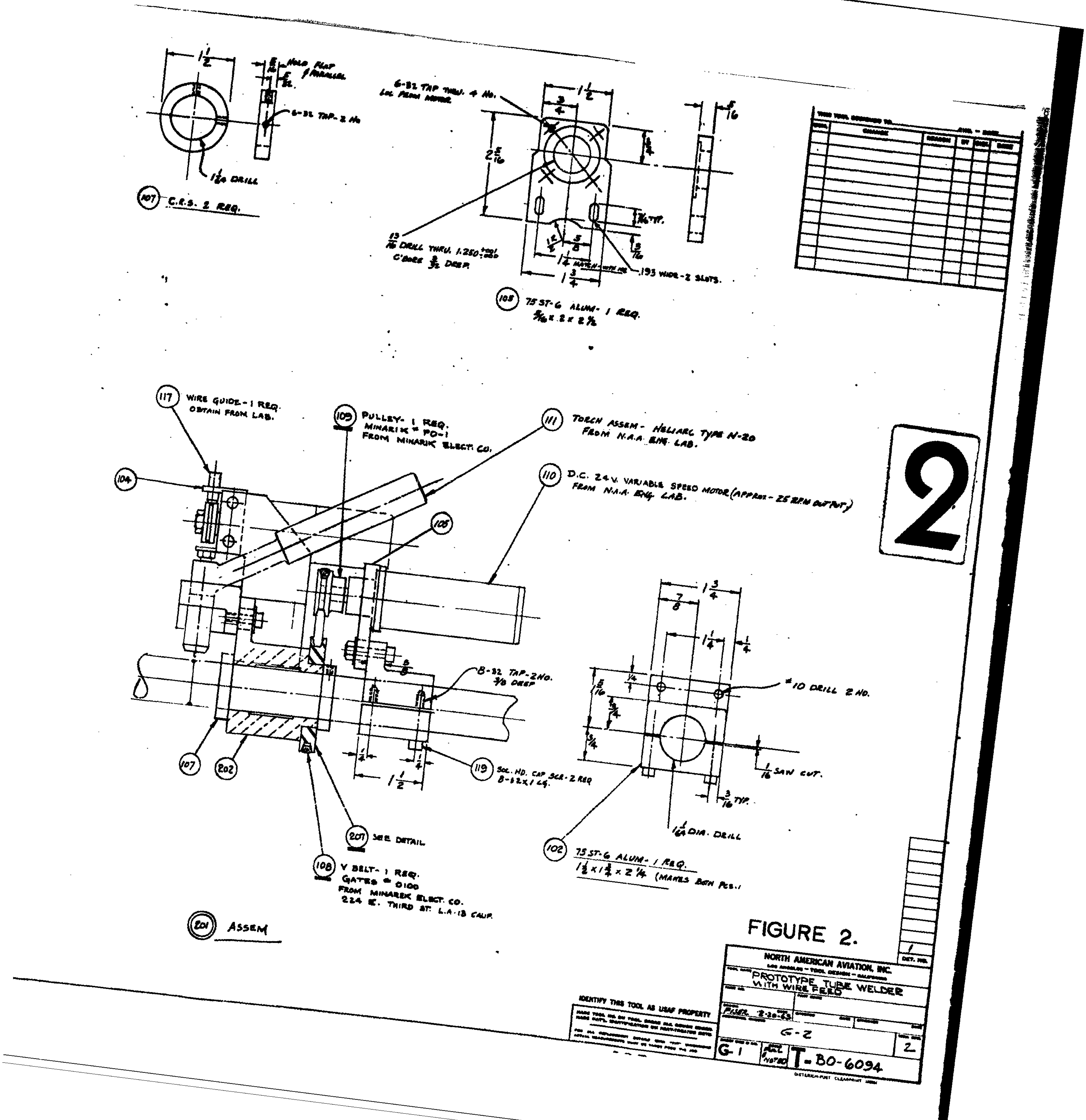
NORTH AMERICAN AVIATION, INC. ENGINEERING INTERNATIONAL AIRPORT LOS ANGELES 45, CALIF.

SCALE FULL & NOTED

DWG SIZE J X-4537



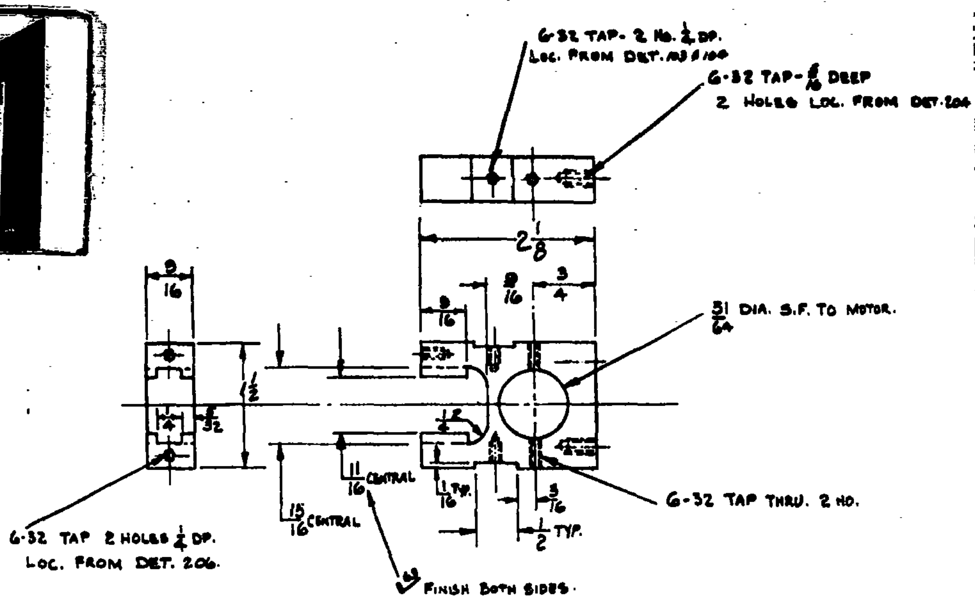
1
DC-24 V. VARIABLE SPEED MOTOR
APPROX. 25 RPM OUT PUT.
ALTER SHAFT TO 1/4 DIA., 1/4 20 THD. END & ADD KEY.
OBTAIN FROM ENG. LAB
HOLD FLAT & PARALLEL
6-32 TAP - 2 No
1 1/64 DRILL
107 C.R.S. 2 REQ.
112 FLAT WASHER - 1/4 STD. 2 REQ.
113 HEX JAM NUT - 2 REQ. 1/4 20
114 TS-846-3 1 REQ.
114 SPRING. 1 REQ. 1/4 O.D. x 1/2 OPEN HT.
117 WIRE GUIDE - 1 REQ. OBTAIN FROM LAB.
1/4 REAM P.F. FOR DET. 117
3/64 DRILL
104 C.R. STRIP ST. - 1 REQ. 1/8 x 1/2 x 1 1/8
115 NYLON TUBING. 1 REQ 1/8 O.D x 3/32 I.D. x 2 LG.
116 TUBING CONNECTOR - 2 REQ. CLIPPARD # 11923 FROM ROGER HOWELL CO. 1804 W. OLIVE, BURBANK CALIF.
10-32 TAP
103 C.R. STRIP ST. 1 REQ. 1/8 x 1/2 x 1 1/8
3/32 DIA.
1/4 HEX.
10-32 TAP 1/8 DEEP
3/64 DRILL
106 C.R.S. 1 REQ. (SCALE 2 TIMES SIZE)
201 ASSEM



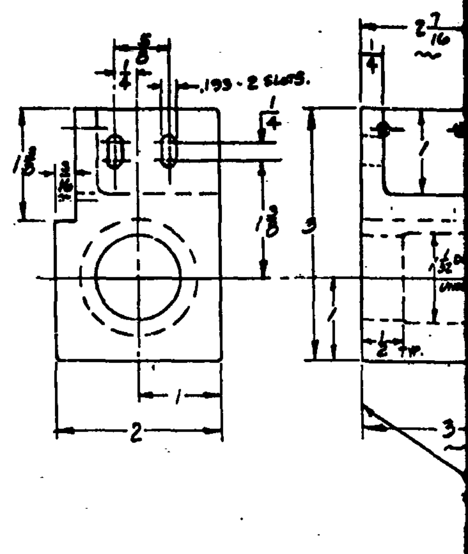
HOLD FLAT & PARALLEL
6-32 TAP - 2 NO.
1/64 DRILL
107 C.R.S. 2 REQ.
6-32 TAP THRU. 4 NO. LOC. FROM MOTOR
13/16 DRILL THRU. 1.250 C'BORE 3/32 DEEP
.193 WIDE - 2 SLOTS.
105 75 ST-6 ALUM - 1 REQ. 5/16 x 2 x 2 5/8
117 WIRE GUIDE - 1 REQ. OBTAIN FROM LAB.
109 PULLEY - 1 REQ. MINARIK # PO-1 FROM MINARIK ELECT. CO.
111 TORCH ASSEM - HELIARC TYPE H-20 FROM N.A.A. ENG. LAB.
110 D.C. 24 V. VARIABLE SPEED MOTOR (APPROX - 25 RPM OUTPUT) FROM N.A.A. ENG. LAB.
104
8-32 TAP - 2 NO. 3/8 DEEP
#10 DRILL 2 NO.
1/16 SAW CUT.
3/16 TYP.
1 1/64 DIA. DRILL
119 SOC. HD. CAP SCR - 2 REQ 8-32 x 1 LG.
107
202
207 SEE DETAIL
102 75 ST-6 ALUM - 1 REQ. 1 1/2 x 1 3/4 x 2 1/4 (MAKES BOTH PCS.)
108 V BELT - 1 REQ. GATES # 0100 FROM MINAREK ELECT. CO. 224 E. THIRD ST. L.A. 13 CALIF.
201 ASSEM
2
IDENTIFY THIS TOOL AS USAF PROPERTY
NORTH AMERICAN AVIATION, INC.
LOS ANGELES - TOOL DESIGN - CALIFORNIA
PROTOTYPE TUBE WELDER WITH WIRE FEED
G-2
G-1
T-BO-6094

FIGURE 2.

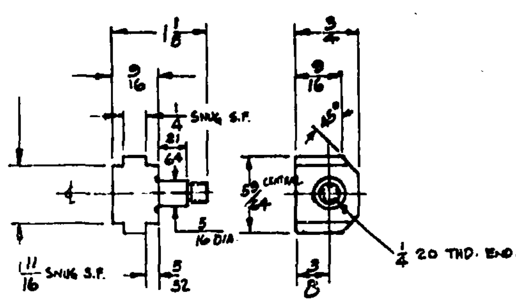
1



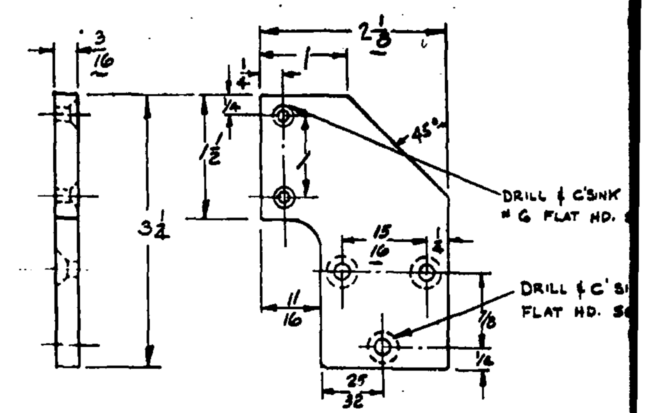
(201) 75 ST-6 ALUM $\frac{5}{8} \times 1\frac{3}{4} \times 2\frac{1}{4}$ - 1 REQ.



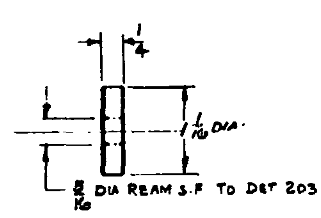
(202) 75 S



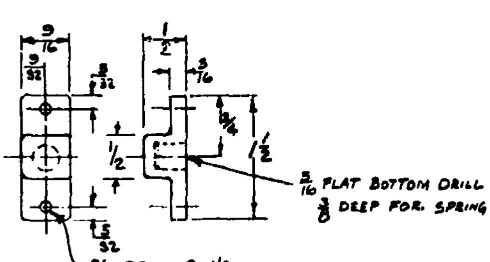
(203) HARD BRASS - 1 REQ.
$\frac{3}{4} \times 1\frac{1}{2} \times 1\frac{1}{4}$



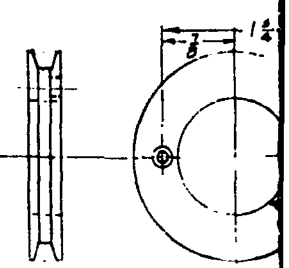
(204) *PHENOLIC LAMINATE - 1 REQ.*
$\frac{3}{16} \times 2\frac{1}{4} \times 3\frac{1}{2}$ -



(205) C.R.S. - 1 REQ



(206) 75 ST-6 ALUM - 1 REQ
$\frac{1}{2} \times \frac{5}{8} \times 1\frac{3}{4}$



(207) ALTER AS SHOWN
MINAREK # PO-2
FROM MINAREK EL

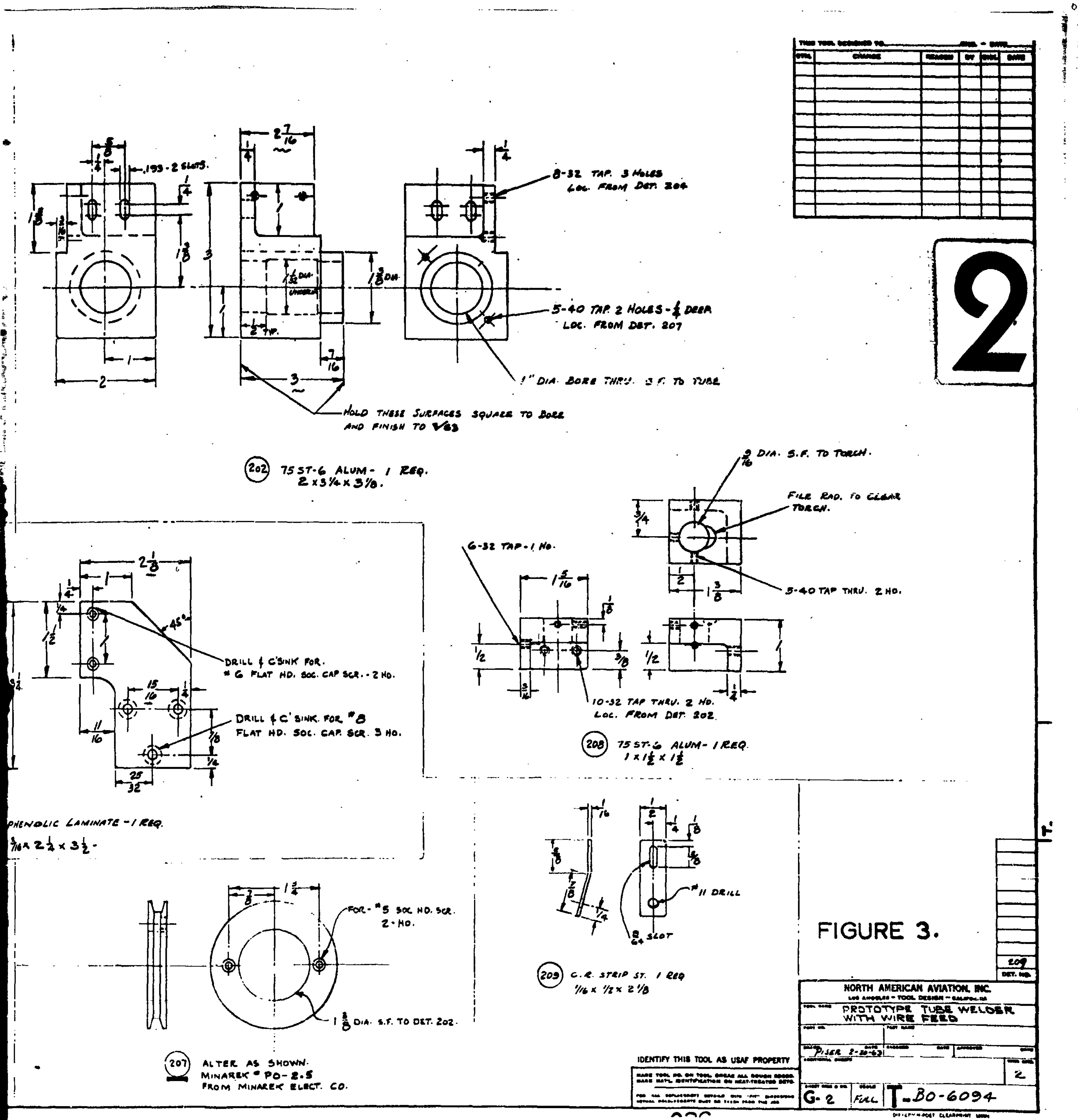
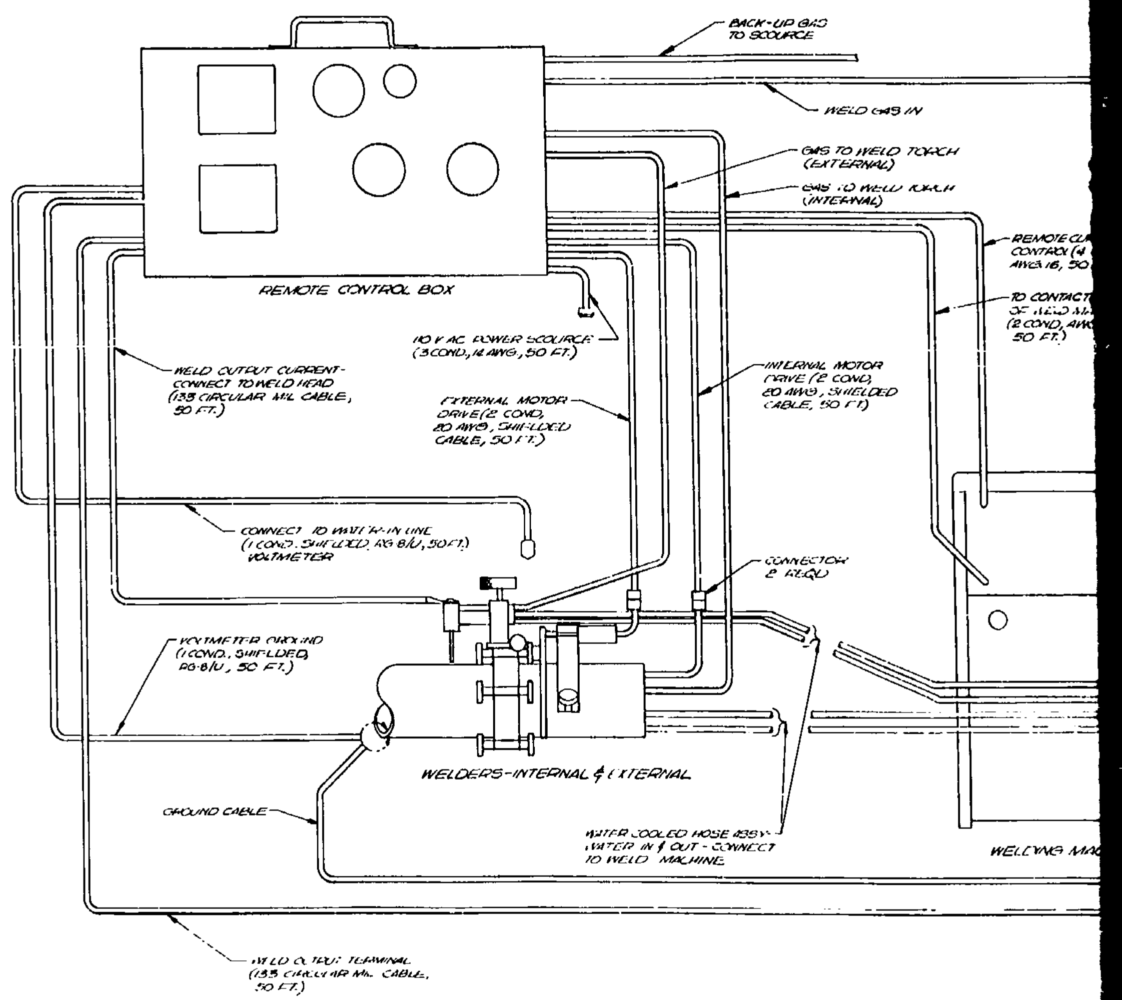

.193 - 2 SLOTS.
8-32 TAP. 3 HOLES
LOC. FROM DET. 204
5-40 TAP. 2 HOLES - 1/4 DEEP
LOC. FROM DET. 207
1" DIA. BORE THRU. S.F. TO TUBE
HOLD THESE SURFACES SQUARE TO BORE
AND FINISH TO √63
202 75 ST-6 ALUM - 1 REQ.
2 x 3 1/4 x 3 1/8.
DRILL & C'SINK FOR.
6 FLAT HD. SOC. CAP SCR. - 2 HO.
DRILL & C'SINK. FOR #8
FLAT HD. SOC. CAP. SCR. 3 HO.
PHENOLIC LAMINATE - 1 REQ.
9/16 DIA. S.F. TO TORCH.
FILE RAD. TO CLEAR
TORCH.
6-32 TAP - 1 HO.
5-40 TAP THRU. 2 HO.
10-32 TAP THRU. 2 HO.
LOC. FROM DET. 202
208 75 ST-6 ALUM - 1 REQ.
1 x 1 1/2 x 1 1/2
FOR - #5 SOC. HD. SCR.
2 - HO.
1 3/8 DIA. S.F. TO DET. 202.
207 ALTER AS SHOWN.
MINAREK # PO-2.5
FROM MINAREK ELECT. CO.
#11 DRILL
5/64 SLOT
209 C.R. STRIP ST. 1 REQ
1/16 x 1/2 x 2 1/8
IDENTIFY THIS TOOL AS USAF PROPERTY
NORTH AMERICAN AVIATION, INC.
TOOL DESIGN
PROTOTYPE TUBE WELDER
WITH WIRE FEED
PISER 2-20-63
G-2
FULL
T-B0-6094
2

FIGURE 3.

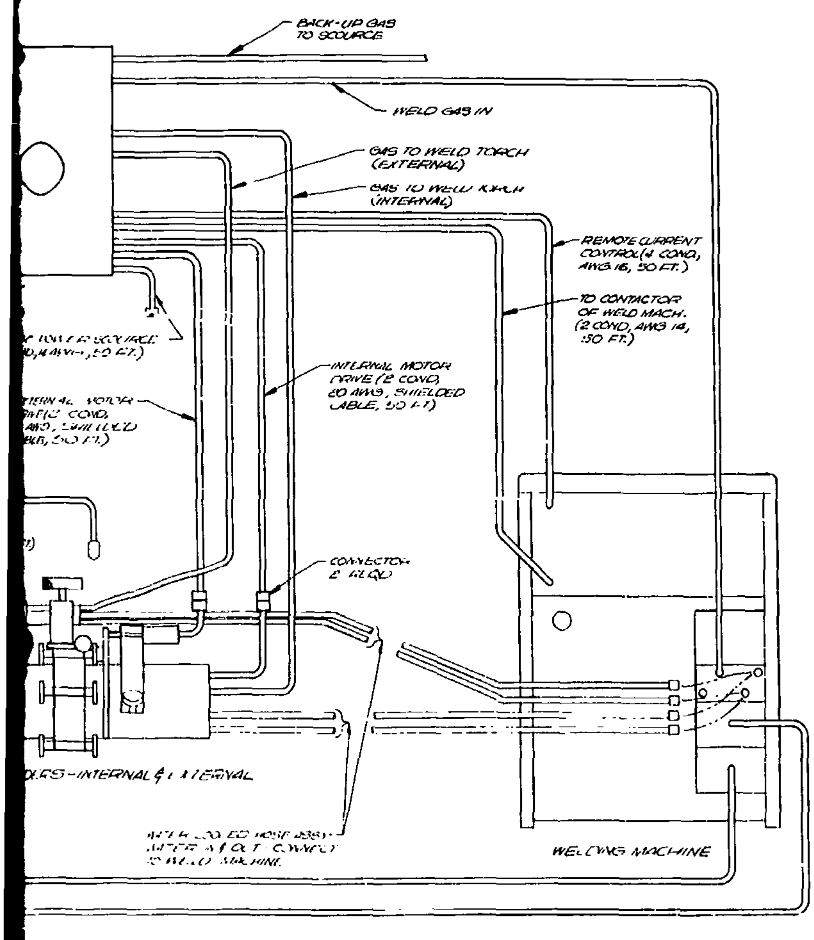


INTERCONNECTING DIAGRAM of REMOTE CONTROL
NO SCALE

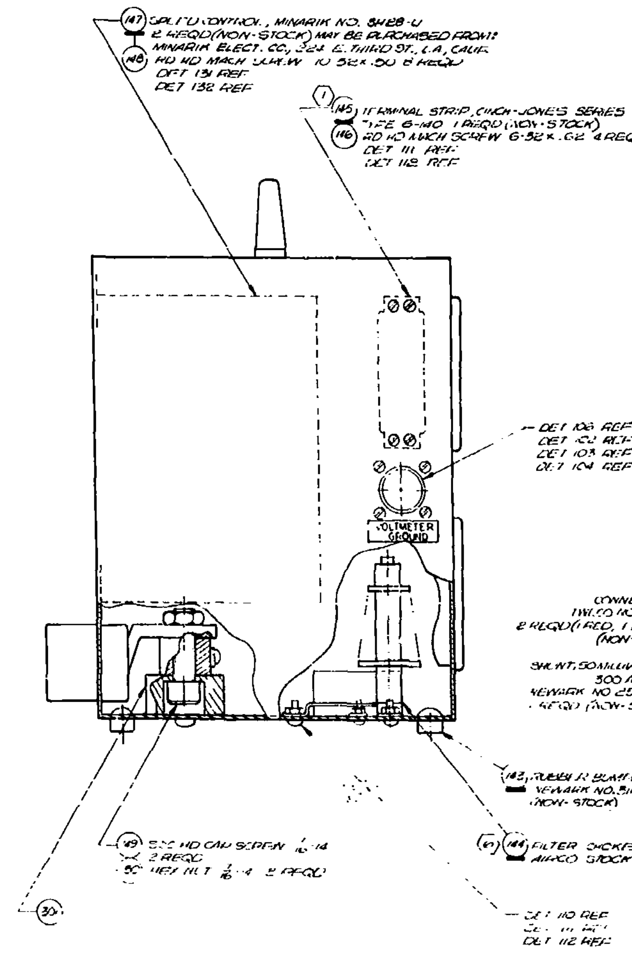
1

10 9 8

2

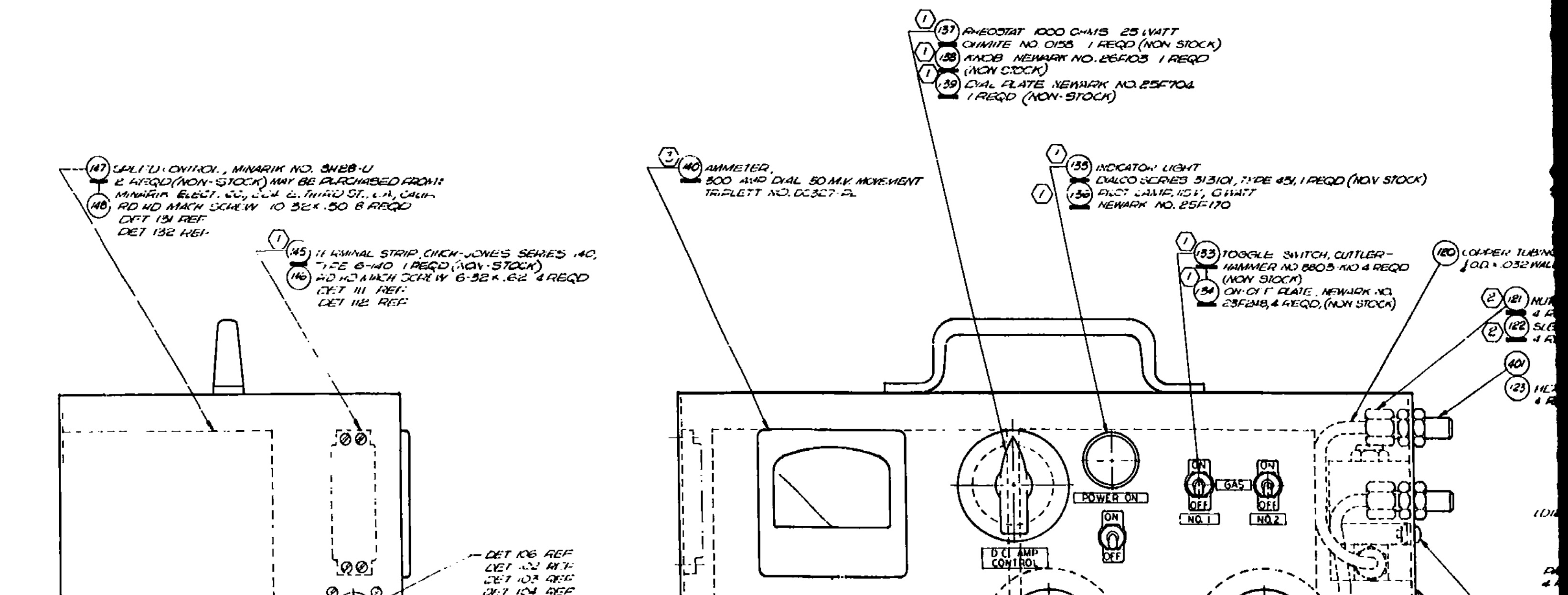


CONNECTING DIAGRAM of REMOTE CONTROL
NO SCALE



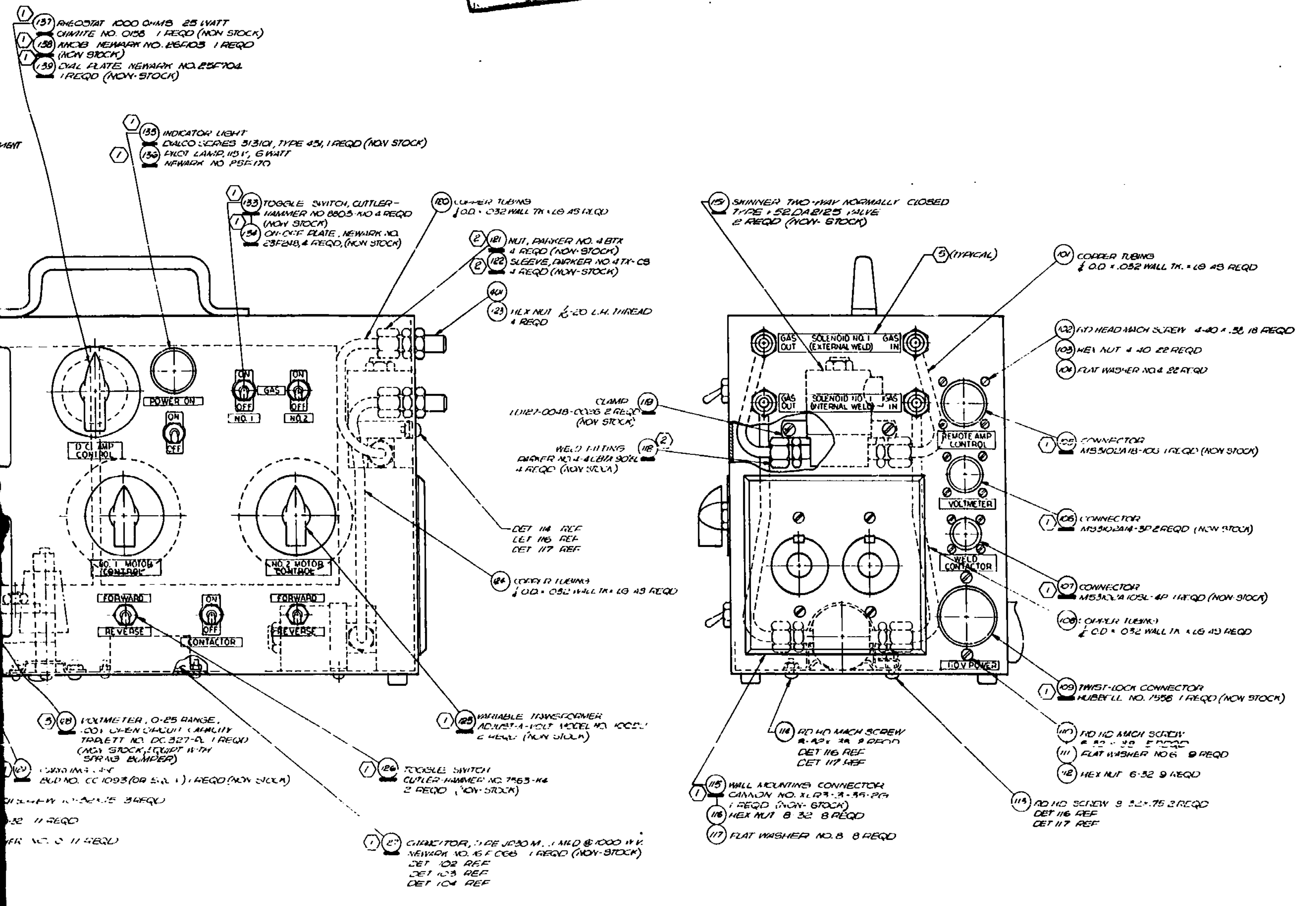
8 7 6

3



RHEOSTAT 1000 OHMS 25 WATT
OHMITE NO. 0155 1 REQD (NON STOCK)
KNOB NEWARK NO. 26F105 1 REQD (NON STOCK)
DIAL PLATE NEWARK NO. 25F704 1 REQD (NON-STOCK)
AMMETER, 500 AMP DIAL 50 M.V. MOVEMENT
TRIPLETT NO. DC327-PL
INDICATOR LIGHT
DIALCO SERIES 513101, TYPE 451, 1 REQD (NON STOCK)
NEWARK NO. 25F170
TOGGLE SWITCH, CUTLER-HAMMER NO 8803-K10 4 REQD (NON STOCK)
ON-OFF PLATE, NEWARK NO. 25F818, 4 REQD, (NON STOCK)
COPPER TUBING
DET 106 REF
DET 102 REF
DET 103 REF
DET 104 REF
VOLTMETER GROUND
POWER ON
ON
OFF
GAS
NO. 1
NO. 2
D C AMP CONTROL
NO. 1 MOTOR CONTROL
NO. 2 MOTOR CONTROL
FORWARD
REVERSE
CONTACTOR
VOLTMETER, 0-25 RANGE,
TRIPLETT NO. DC 327-PL 1 REQD
(NON-STOCK, EQUIPT WITH SPRING BUMPER)
BUD NO. CC-1093 (OR EQUIV) 1 REQD (NON STOCK)
TOGGLE SWITCH
CUTLER-HAMMER NO. 7565
FILTER CHOKE 4 MIL-HENRY
RD HD MACH SCREW 10-32 x .75 3 REQD
HEX NUT 10-32 11 REQD
FLAT WASHER NO. 10 11 REQD
CAPACITOR, TYPE JD30
NEWARK NO. 16 F 066
DET 102 REF
DET 103 REF
DET 104 REF
6
5
4

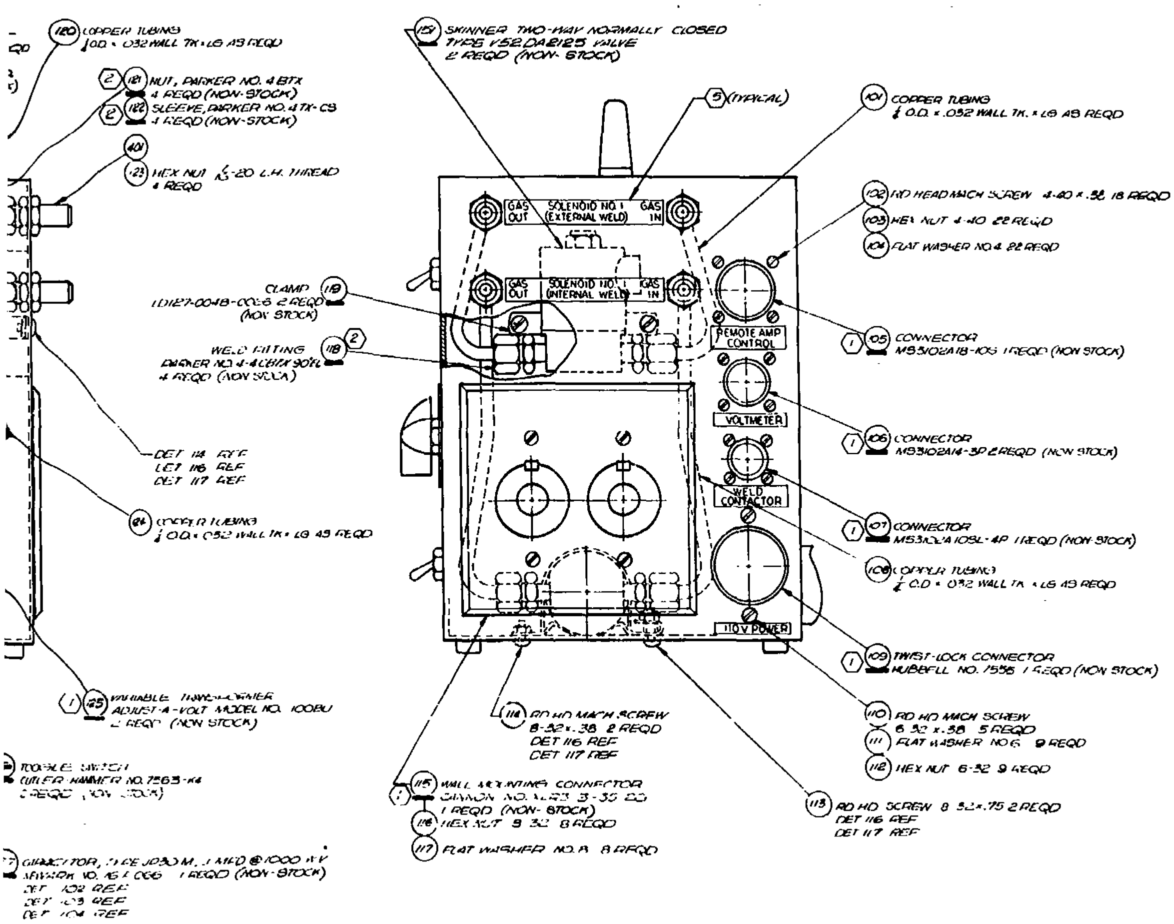
4



137 RHEOSTAT 1000 OHMS 25 WATT OHMITE NO. 0158 1 REQD (NON STOCK)
138 KNOB NEWARK NO. 26F103 1 REQD (NON STOCK)
139 DIAL PLATE NEWARK NO. 25F704 1 REQD (NON-STOCK)
135 INDICATOR LIGHT DIALCO SERIES 513101, TYPE 451, 1 REQD (NON STOCK)
136 PILOT LAMP, 115 V, 6 WATT NEWARK NO PSF170
133 TOGGLE SWITCH, CUTLER-HAMMER NO 8803-K10 4 REQD (NON STOCK)
134 ON-OFF PLATE, NEWARK NO. 23F218, 4 REQD, (NON STOCK)
120 COPPER TUBING
121 NUT, PARKER NO. 4 BTX 4 REQD (NON-STOCK)
122 SLEEVE, PARKER NO 4 TX-CS 4 REQD (NON-STOCK)
123 HEX NUT
4 REQD
POWER ON
ON
OFF
NO. 1
GAS
NO. 2
D C AMP CONTROL
NO. 1 MOTOR CONTROL
NO. 2 MOTOR CONTROL
FORWARD
REVERSE
CONTACTOR
CLAMP
WELD FITTING
DET 114 REF
DET 116 REF
DET 117 REF
124 COPPER TUBING
128 VOLTMETER, O-25 RANGE,
TRIPLETT NO. DC 327-PL 1 REQD
(NON STOCK, EQUIPT WITH SPRAG BUMPER)
125 VARIABLE TRANSFORMER
126 TOGGLE SWITCH CUTLER-HAMMER NO. 7563-K4 2 REQD (NON-STOCK)
127 CAPACITOR
DET 102 REF
DET 103 REF
DET 104 REF
151 SKINNER TWO-WAY NORMALLY CLOSED
2 REQD (NON-STOCK)
5 (TYPICAL)
101 COPPER TUBING
GAS OUT
SOLENOID NO. 1 (EXTERNAL WELD)
GAS IN
SOLENOID NO. 1 (INTERNAL WELD)
102 RD HEAD MACH SCREW 4-40 x .38 18 REQD
103 HEX NUT 4 40 22 REQD
104 FLAT WASHER NO 4 22 REQD
REMOTE AMP CONTROL
105 CONNECTOR
VOLTMETER
106 CONNECTOR
WELD CONTACTOR
107 CONNECTOR
108 COPPER TUBING
110 V POWER
109 TWIST-LOCK CONNECTOR HUBBELL NO. 7556 1 REQD (NON STOCK)
110 RD HD MACH SCREW
111 FLAT WASHER NO 6 9 REQD
112 HEX NUT 6-32 9 REQD
114 RD HD MACH SCREW
DET 116 REF
DET 117 REF
115 WALL MOUNTING CONNECTOR
1 REQD (NON-STOCK)
116 HEX NUT 8 32 8 REQD
117 FLAT WASHER NO. 8 8 REQD
113 RD HD SCREW
DET 116 REF
DET 117 REF

5 4 3 2

5



(7) 8. MAY BE PURCHASED FROM: HASKEL ENGINEERING, 1236 S. CENTRAL AVE. GLENDALE 4, CALIF.

(6) 7. MAY BE PURCHASED FROM: AIRCO WELDING EQUIPMENT 2861 LEONIS AVE VERNON 58, CALIF.

(5) 6. ENGRAVE .12 HIGH WHITE LETTERS ON BLACK PLASTIC ENGRAVING STOCK. LOCATE APPROXIMATELY AS SHOWN.

5. SCALE DRAWING FOR DIMENSIONS

(4) 4. MAY BE PURCHASED FROM: [illegible] SUPPLIES, 2202 S GARFIELD, L.A., CALIF.

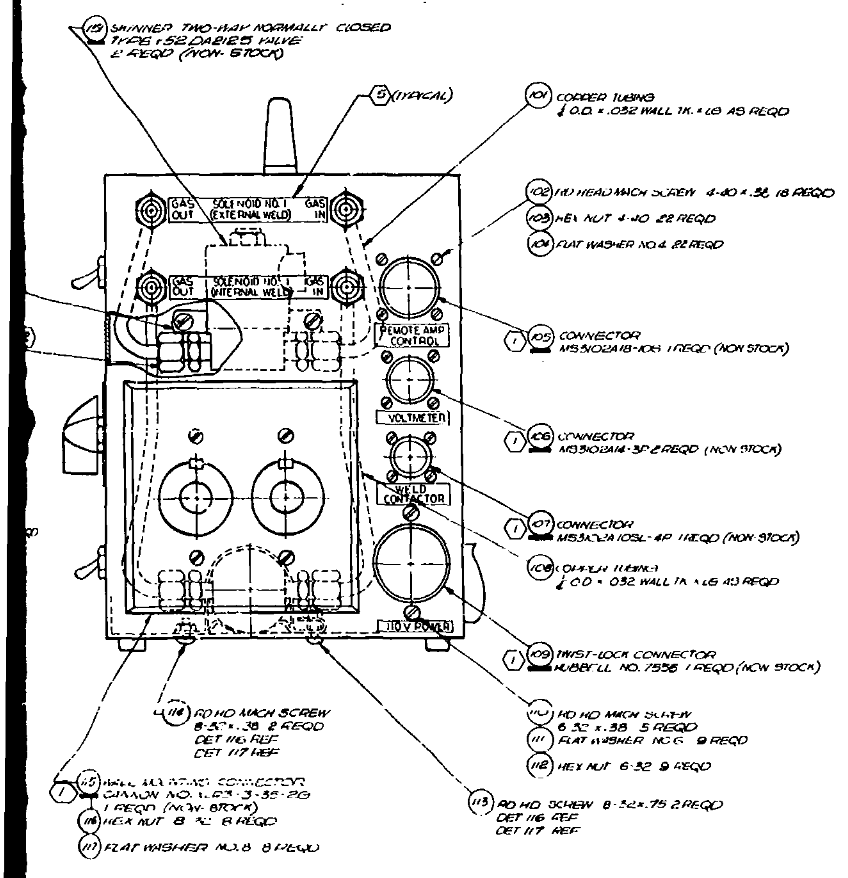
(3) 3. MAY BE PURCHASED FROM: [illegible] INDUSTRIES 1016 W. 8TH ST, LOS ANGELES, CALIF.

(2) 2. MAY BE PURCHASED FROM: METROPOLITAN SUPPLY CO., 355 E. 2nd ST., LOS ANGELES 12, CALIF.

(1) 1. MAY BE PURCHASED FROM: NEWARK ELECTRONICS CO., 4747 W. CENTURY BLVD, INGLEWOOD, CALIF

NOTES: UNLESS OTHERWISE SPECIFIED

4 3 2



7 8. MAY BE PURCHASED FROM: HASKEL ENGINEERING, 1236 S. CENTRAL AVE. GLENDALE 4, CALIF.

6 7. MAY BE PURCHASED FROM: AIRCO WELDING EQUIPMENT 2861 LEONIS AVE VERNON 58, CALIF.

5 6. ENGRAVE .12 HIGH WHITE LETTERS ON BLACK PLASTIC ENGRAVING STOCK, LOCATE APPROXIMATELY AS SHOWN.

5. SCALE DRAWING FOR DIMENSIONS

4 4. MAY BE PURCHASED FROM: AIRCO WELDING SUPPLIES, 2202 S GARFIELD, L.A., CALIF.

3 3. MAY BE PURCHASED FROM: ARROW INDUSTRIES. 1016 W. 8TH ST, LOS ANGELES, CALIF.

2 2. MAY BE PURCHASED FROM: METROPOLITAN SUPPLY CO., 355 E. 2nd ST., LOS ANGELES 12, CALIF.

1 1. MAY BE PURCHASED FROM: NEWARK ELECTRONICS CO., 4747 W. CENTURY BLVD, INGLEWOOD, CALIF.

NOTES: UNLESS OTHERWISE SPECIFIED

6

FIGURE 4.

NORTH AMERICAN AVIATION INC.

WELD CONTROL BOX

JR-1 FULL 130 8063

4. WELDING PROCEDURE REQUIREMENTS

4.1 Inert Shielding Gas. An inert shielding gas such as commercially pure helium, welding grade argon (MIL-A-18455), or a premixed bottled gas composed of 75 percent Argon and 25 percent Helium, shall be used as the inert gas for all shielded arc welding operations. The Argon-Helium mixture is preferred in order to minimize weld bead width and to facilitate arc initiation.

4.2 Tungsten Electrodes. Two percent thoriated tungsten electrodes shall be used for all welding operations.

4.3 Joint Preparation. The weld joint and, where required, the filler material shall be prepared and cleaned as described in the following paragraphs.

4.3.1 Preparation of Tube Ends. The tube ends to be welded shall be machined square within the limits described below and deburred by hand filing prior to welding. When the wall thickness of the tubing is too thin to permit satisfactory machining (0.010 inch and less), the joint preparation shall be accomplished by draw filing only. The tube ends should be normal to the axis of the tubes within the limits shown in Table II. These limits are established for the welding parameters given in Table V.

TABLE II. PREPARATION OF TUBE ENDS FOR WELDING.

TUBING MATERIAL	NOMINAL TUBING DIMENSIONS		TUBE END FINISHING PROCEDURE	TUBE END SQUARENESS TOLERANCE (Inches)
	OD (Inches)	WALL THICKNESS (Inches)		
AISI 321 Stainless Steel	1/8 3	0.010 0.070	Drawfiling Machining	0.003 0.010
AISI 347 Stainless Steel	1 3	0.083 0.250	Machining Machining	0.008 0.010
AM 350 Stainless Steel	1/4 1	0.042 0.134	Machining Machining	0.008 0.005
Rene' 41 Alloy	1/8 3/4	0.010 0.030	Drawfiling Machining	0.003 0.008
6061 Aluminum Alloy	1	0.058	Machining	0.002

4.3.2 Preparation of Filler Material. Filler metal may be added either in the form of fitted sleeves or as wire. Sleeves are finish machined to ensure a slip fit. This slip fit tolerance requirement is based on the diametrical tolerance to which the tubing can be produced. Recommended sizes for sleeve fittings and filler wire diameter are given in Table III.

4.3.3 Cleaning Requirements. The tube ends to be welded and the areas immediately adjacent shall be free from all foreign substances, including oxides, dirt, grease, oil, marking inks and pencil marks. The weld tooling that is in close proximity to the weld area shall be cleaned to the same requirements. The cleaning procedures are described below.

4.3.3.1 Stainless Steel. Weld joints in AISI 321, AISI 347, and AM 350 stainless steel tubing shall be stainless steel wire brushed to remove any foreign substances and then wiped clean with acetone or other clean organic solvent prior to welding.

4.3.3.2 Rene' 41 Alloy. Weld joints in Rene' 41 alloy tubing shall be wire brushed and then hand sanded with 1/0 grade garnet paper to remove any foreign substances, and then wiped clean with acetone or other clean organic solvent prior to welding.

4.3.3.3 Aluminum Alloy. Weld joints in 6061 aluminum alloy tubing shall be wiped clean with acetone and coated with Solar 202 flux prior to welding. After completion of the welding operation, the flux shall be removed by flushing with hot water.

4.3.4 Preweld Joint Assembly

4.3.4.1 Alignment of the tube ends is automatically accomplished when a preplaced fitted sleeve is used. The midpoint of the sleeve shall be located within $\pm$ 1/16 inch of the weld joint centerline for sleeve lengths greater than 1/2 inch. For sleeve lengths less than 1/2 inch, the midpoint of the sleeve shall be located within $\pm$ 1/32 inch of the weld joint centerline.

4.3.4.2 When a preplaced fitted sleeve is not used, alignment of the tube ends must be accomplished by the weld tool. Fusion tack welds may also be used for this purpose where they do not contribute to decreased joint quality. The maximum allowable gap between the butted tube ends for the several tubing sizes is given in Table IV.

4.4 Welding of Tubing

4.4.1 Certification Procedure

4.4.1.1 To establish that a satisfactory weld schedule has been developed at least three test welds must be made in order to determine that a consistent weld is produced.

TABLE III. RECOMMENDED SIZES FOR WELD JOINT SLEEVE FITTINGS AND FILLER WIRE.

TUBING MATERIAL	NOMINAL TUBING DIMENSIONS		DIMENSIONS OF SLEEVE FITTINGS			METHOD OF FABRICATING SLEEVE FITTINGS (a)
	OD (Inches)	WALL THICKNESS (Inches)	ID (Inches)	WALL THICKNESS (Inches)	LENGTH (Inches)	
AISI 321 Stainless Steel	1/8	0.010	0.127 +.001 -.000	0.012 +.002 -.000	1/2	M
	3	0.070	3.010 ±.005	0.050 +.005 -.000	1	E
AISI 347 Stainless Steel	1	0.083	1.003 +.003 -.000	0.030 +.005 -.000	1	E
	3	0.250	(b)	(b)	(b)	(b)
AM 350 Stainless Steel	0.250	0.042	0.252 +.003 -.000	0.015 +.003 -.000	1/2	M
	1	0.134	(c)	(c)	(c)	(c)
Rene' 41 Alloy	1/8	0.010	0.129 +.001 -.000	0.010 +.002 -.000	3/8	M
	3/4	0.030	0.753 +.002 -.000	0.030 +.005 -.000	1	E
6061 Aluminum Alloy	1	0.058	(d)	(d)	(d)	(d)

Notes: (a) Method "E" is to expand length of tubing being joined, and then finish machine expanded tubing to final dimensions.
Method "M" is to machine sleeve from bar stock.
(b) Sleeve fitting not used. Joint made by welding from both inside and outside of tubing. No filler material added to joint.
(c) Sleeve fitting not used. Joint made by welding from outside of tube only. No filler material added to joint.
(d) Sleeve fitting not used. Joint made by welding from outside of tube only. 4043 aluminum alloy added to joint as filler material in form of 0.045 inch diameter wire.

TABLE IV.

MAXIMUM GAP ALLOWED BETWEEN BUTTING TUBE ENDS.

TUBING MATERIAL	NOMINAL TUBING DIMENSIONS OD (INCHES)	NOMINAL TUBING DIMENSIONS WALL THICKNESS (INCHES)	MAXIMUM GAP ALLOWED BETWEEN BUTTING TUBE ENDS (INCHES)
AISI 347 STAINLESS STEEL	1	0.083	0.030
	3	0.250	0.030
AM 350 STAINLESS STEEL	1/4	0.042	0.010
	1	0.134	0.010
RENE'41 ALLOY	1/8	0.010	0.004
6061 ALUMINUM ALLOY	1	0.058	0.004

4.4.1.2 After visual and radiographic inspection of the test welds have indicated that the weld quality is satisfactory, all of the final weld variables are recorded. This certified final weld schedule then may be used for other identical applications at a later date after making only one test joint to ensure satisfactory weld quality. Satisfactory quality of such test joints must be determined by visual and radiographic inspection.

4.4.2 The recommended welding parameters for the tubing materials and sizes covered by this specification are given in Table V.

5. QUALITY CONTROL

5.1 Radiographic Inspection (Weld Deposit Quality Requirements). All weldments in systems considered to be critical shall be inspected for acceptance or rejection based upon the following criteria.

5.1.1 Cracks of any size in the weld metal or adjacent to the weld bead are not acceptable.

5.1.2 Lack or fusion and/or lack of penetration is not acceptable.

5.1.3 Porosity

5.1.3.1 Single Cavity Porosity. Single porosity cavities are acceptable provided the cavity does not measure more than 1/3 of the thickness of the thinnest material of the joint, or 0.040 inch, whichever is smaller. Interconnected porosity shall be considered as a single cavity. Measurement of all porosity cavities shall be based on the largest dimension.

5.1.3.2 Linear Porosity. Where three or more porosity cavities are in alignment and their radiographic images measure between 10 and 33 percent of the tube wall thickness, or 0.040 inch, whichever is smaller, the sum of their areas must not exceed 2.5 percent of a unit area of one times the tube wall thickness.

5.1.3.3 Scattered Porosity. The sum of the areas of all the cavities contained in a one-inch length of weld must not exceed five percent of a unit area of one times the tube wall thickness.

5.1.4 Inclusions

5.1.4.1 Both tungsten and non-metallic inclusions shall be subject to the same dimensional limitations defined in paragraph 5.1.3 for porosity. Where both inclusions and porosity are present, the total of their combined lengths shall be within the limitations for porosity alone.

5.1.4.2 Inclusions having sharp corners or tails are not acceptable.

5.2 Visual Inspection. Both production and certification welding of tube joints using the joint preparation techniques of paragraph 4.3 and the weld schedules of Table V should result in weld bead contours which are within the ranges given in Table VI.

TABLE V. WELD PARAMETERS FOR AUTOMATIC TIG WELDING OF TUBING JOINTS.

TUBING SYSTEM MATERIAL	TUBING SIZE (Inches) OD	WALL	TYPE OF FILLER ADDITION	TYPE OF WELD AND NUMBER OF WELD PASSES	ELECTRODE DIAMETER (Inches)	WELDING CURRENT (Amperes)	ARC VOLTAGE (Volts) (a)	TRAVEL (Second Revolu
AISI 347 Stainless Steel	1	0.083	0.030 inch thick sleeve	External 1 pass	3/32	84	10.0	26.
	3	0.250	None	Internal 1 pass plus External 1 pass	3/32 3/32	100 110	9.5 9.5	180. 210.
AM 350 CRT Stainless Steel	1/4	0.042	0.015 inch thick sleeve	External 1 pass	1/16	15 (c)	12.0	17.
AM 350 SCT Stainless Steel	1	0.134	None	External 2 passes: 1st pass 2nd pass	3/32	95 55	14.0 14.0	45. 45.
Rene' 41 Alloy	1/8	0.010	0.010 inch thick sleeve	External 1 pass	1/16	5 (c)	18.0	8.
	3/4	0.030	0.030 inch thick sleeve	External 1 pass	1/16	40	12.0	24.
6061-T6 Aluminum	1	0.058	Wire Feed (e) (f)	External (f)	1/16	26 (f)	13.0	48.0

Notes:

(a) The welding voltage is fixed prior to welding by manual adjustment of the arc length (gap be

(b) Number denotes electrode position in terms of hour positions of clock. Electrode travel is otherwise noted.

(c) Electrode travel started before weld current initiated.

(d) Purged 5 minutes in inert atmosphere chamber, backup gas was started just prior to beginning

(e) 4043 aluminum alloy, 0.045 inch diameter filler wire. Wire feed was at rate of 12 inches pe speed of 4 inches per minute counterclockwise direction travel.

(f) Current of 20 amperes was used to preheat start area for 20 seconds; then current was increa electrode travel and wire feed were started within 5 seconds. Approximately 2/3 way around reduced to compensate for effect of preheating ahead of electrode. After overlapping weld s then weld current was sloped off to zero by the time required to complete approximately 1/2

LD PARAMETERS FOR AUTOMATIC TIG WELDING OF TUBING JOINTS.

TYPE OF WELD AND NUMBER OF WELD PASSES	ELECTRODE DIAMETER (Inches)	WELDING CURRENT (Amperes)	ARC VOLTAGE (Volts) (a)	TRAVEL SPEED (Seconds per Revolution)	WELDING START POSITION (b)	SHIELDING GAS AND FLOW RATE		PURGE TIME (Minutes)
						TORCH	BACKUP	
External 1 pass	3/32	84	10.0	26.5	6:00	75% Argon 25% Helium 20 c.f.h.	Helium 40 c.f.h.	5
Internal 1 pass plus External 1 pass	3/32	100	9.5	180.0	6:00	75% Argon 25% Helium 50 c.f.h.	Helium 50 c.f.h.	1
	3/32	110	9.5	210.0	12:00	75% Argon 25% Helium 60 c.f.h.	Helium 40 c.f.h.	3
External 1 pass	1/16	15 (c)	12.0	17.0	Traveling	75% Argon 25% Helium 20 c.f.h.	Helium 50 c.f.h.	10
External 2 passes: 1st pass / 2nd pass	3/32	95 / 55	14.0 / 14.0	45.0 / 45.0	7:30	75% Argon 25% Helium 40 c.f.h.	Helium 50 c.f.h.	15
External 1 pass	1/16	5 (c)	18.0	8.5	Traveling	75% Argon 25% Helium 15 c.f.h.	Helium 30 c.f.h.	10
External 1 pass	1/16	40	12.0	24.5	9:00	Argon 10 c.f.h.	Helium 75 c.f.h.	(d)
External (f)	1/16	26 (f)	13.0	48.0 (e)	11:00 (e) (f)	Helium 50 c.f.h.	Argon 30 c.f.h.	1

to welding by manual adjustment of the arc length (gap between welding electrode and work).
n terms of hour positions of clock. Electrode travel is in clockwise direction unless

d current initiated.

e chamber, backup gas was started just prior to beginning welding.

meter filler wire. Wire feed was at rate of 12 inches per minute for electrode traveling
rclockwise direction travel.

reheat start area for 20 seconds; then current was increased to 26 amperes, after which
started within 5 seconds. Approximately 2/3 way around circumference, weld current was
preheating ahead of electrode. After overlapping weld start, wire feed was sloped off,
zero by the time required to complete approximately 1/2 a revolution.

2

TABLE VI. WELD BEAD CONTOUR REQUIREMENTS.

TUBING MATERIAL	NOMINAL TUBING DIMENSIONS		WELD BEAD CONTOUR			
					WIDTH OF WELD BEAD	
	OD (Inches)	WALL THICKNESS (Inches)	MAXIMUM BUILD-UP (Inches)	MAXIMUM CONCAVITY (Inches)	MINIMUM (Inches)	MAXIMUM (Inches)
AISI 347 Stainless Steel	1	0.083	0.020	0.010	0.125	0.250
	3	0.250	0.040	0.000	0.150	0.325
AM 350 Stainless Steel	1/4	0.042	0.005	0.010	0.070	0.100
	1	0.134	0.025	0.015	0.180	0.300
Rene' 41 Alloy	1/8	0.010	0.000	0.010	0.060	0.080
	3/4	0.030	0.040	0.020	0.125	0.180
6061 Aluminum Alloy	1	0.058	0.040	0.000	0.150	0.300

APPENDIX VI

TUBE BRAZING SPECIFICATION

SPECIFICATION FOR

INDUCTION BRAZING OF TUBING JOINTS

1. SCOPE

1.1 This specification describes the procedure for induction braze joining of corrosion-resisting steel and nickel-base alloy tubing and fittings for use in Rocket Propulsion Fluid Systems.

2. APPLICABLE MATERIALS AND EQUIPMENT

2.1 Tubing Materials

MIL-T-8808	Tubing, Steel, Corrosion-Resistant (18-8 Stabilized), Aircraft Hydraulic Quality (ASG), Comp 347, Type I or II
AMS 5554	Tubing, Seamless -- 16.5Cr, 4.5Ni, 2.9Mo, 0.1N (AM 350)
Commercial	Tubing, Alloy, Corrosion and Heat Resistant, Nickel Base, Rene' 41 (AMS 5712 may be referenced for material from which tubing is made).

2.2 Fitting Materials

QQ-S-763	Steel Bars, Shapes, and Forgings -- Corrosion Resisting, Class 347, Condition A
AMS 5712	Bars and Forgings -- Nickel Base 19Cr, 11Co, 10Mo, 3Ti, 1.5 Al -- Vacuum Melted, Solution Treated (Rene' 41)
AMS 5743	Bars and Forgings -- 15.5Cr, 4.5Ni, 2.9Mo, 0.1N (AM 355)

2.3 Brazing Alloys

Silver-Copper Eutectic plus Lithium -- 71.8Ag, 28.0Cu, 0.2Li

Gold-Nickel Base plus Lithium -- 81.7Au, 18.0Ni, 0.3Li

Gold-Nickel-Palladium -- 70.0Au, 22.0Ni, 8.0Pd

2.4 Purging Gas

MIL-A-18455 Argon, Technical

2.5 Induction Generating Equipment

2.5.1 Power Rating. The size of the induction generating equipment needed, in terms of power requirements, is dependent upon the coupling of the induction work coil to the workpiece and also upon the diameter and length of the joint. Sufficient power is required to ensure adequate heating of the joints to be brazed in the required time cycle as specified in paragraph 9.2.2. In general, 10 Kw of output power per inch of tubing diameter, as shown in Figure 1, is more than sufficient for all work including remote brazing.

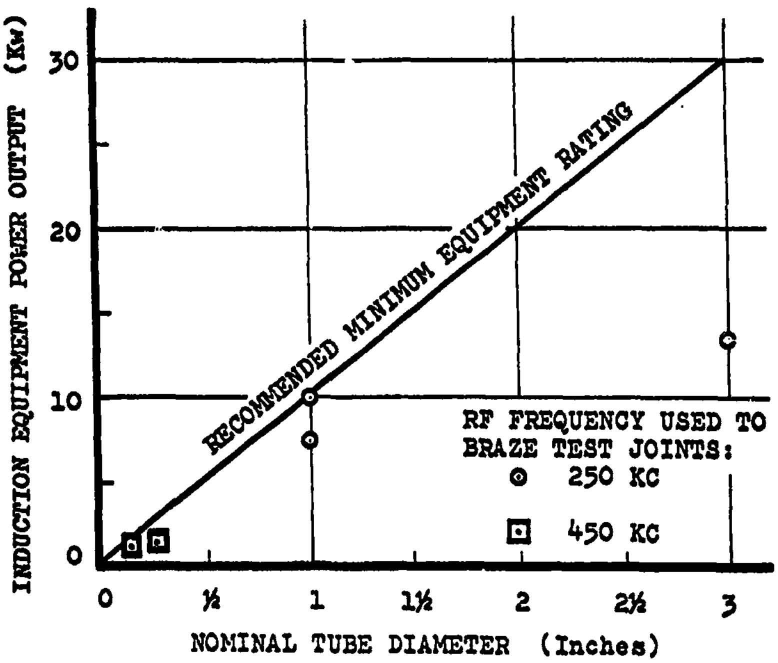


Figure 1. Recommended Rating in Kw of Output Power of Induction Generating Equipment Vs. Nominal Tube Diameter to be Joined by Brazing.

2.5.2 RF Output Frequency. This specification covers only those power sources which utilize RF Output Power frequencies of 250 KC to 450 KC per second, although other RF Output Power Frequency equipment may be used provided the heat-time cycle specified in paragraph 9.2.2 is properly developed.

2.6 Brazing Tools

2.6.1 Induction heating work coils are made from annealed thin-wall copper tubing. The coils are wound (usually over a mandrel) to the diameter, number of turns, and spacing requirements for the particular tubing alloy and size which is being joined, as shown in Table I.

2.6.2 The plenum chamber shall be designed so that an adequate seal can be maintained to keep contaminating gases away from the heated joint area, and proper coupling can be maintained between the induction work coil and the workpiece. The actual dimensions of the plenum chamber are not critical provided the atmosphere seal and coil coupling can be maintained. Suggested plenum chamber dimensions are given in Table I.

2.6.3 A schematic diagram of a typical tubing joint induction braze tooling set-up is shown in Figure 2.

3. PREBRAZE JOINT REQUIREMENTS

3.1 Tubing size and fitting component dimensions shall be as required to meet the operational conditions of the specific rocket propulsion fluid system in which they are to be used. Dimensions of typical fitting sleeves for use with the tubing materials covered by this specification are shown in Table II.

3.2 The clearance between the outside diameter of the tubing and the inside diameter of the fitting sleeve locating land (capillary clearance land) shown in Figure 3 is important to proper flow of the braze alloy and the resultant quality of the brazed joint. The required joint clearance to be maintained for the tubing materials covered by this specification are given in Table III.

3.3 The tubing and fitting materials to be brazed shall be in the heat treat condition shown in Table IV prior to brazing.

4. CLEANING OF PARTS TO BE BRAZED

4.1 General

Clean surfaces are essential if repeatable high quality brazed joints are to be fabricated. Parts to be brazed shall have their surfaces cleaned to remove all rust, scale, oxides, oils, and other contaminants. The cleaning procedures which can be used to prepare the surfaces of parts to be brazed are described in paragraphs 4.2, 4.3, 4.4, and 4.5. The hot alkaline cleaning procedure describedin paragraph 4.2 is the simplest procedure and is recommended wherever it is adequate. The electrolytic cleaning procedures

TABLE I. DIMENSIONS OF TOOLING USED FOR INDUCTION BRAZING OF TUBING JOINTS.

TUBING MATERIAL TO BE BRAZED	SPECIMEN DIMENSIONS		PYREX PLENUM CHAMBER DIMENSIONS (a)		DIMENSIONS OF INDUCTION HEATING COIL				
	TUBE OD	FITTING OD	OUTSIDE DIAMETER	WALL THICKNESS	TUBE SIZE OD	NO. OF COIL TURNS	OVERALL COIL LENGTH	INSIDE DIAMETER OF COIL	COIL TURN SPACING TO
AISI Type 347 Stainless Steel	1.000	1.255	38 mm (1.496 in.)	2.0 mm (0.079 in.)	1/4	5	1-7/8	1-9/16	3/8
	3.000	3.720	Plastic bag used as plenum chamber (d)		1/4	7 (b)	5-5/8 (b)	End Coils 3-3/4 Center Coils 4-1/4	End Coils 1/2 (b) Center Coils 7/16
AM 350 CRT Stainless Steel	0.250	0.400	18 mm (0.709 in.)	1.3 mm (0.051 in.)	1/8 (c)	3	3/8	23/32	1/8
AM 350 SCT Stainless Steel	1.000	1.304	38 mm (1.496 in.)	2.0 mm (0.079 in.)	1/4	3	1-1/4	1-9/16	7/16
Rene' 41 Alloy	0.125	0.187	10 mm (0.394 in.)	1.0 mm (0.039 in.)	1/8	2	7/16	13/32	5/16

Notes: (a) Glass tubing for these plenum chambers is procured to millimeter size dimensional standards. Dimensions in inches are shown for information only.

(b) The two coil turns at each end are separated from the three center coil turns by 1-3/4 inch.

(c) Tubing flattened to an oval shape to obtain proper spacing and coupling. Tubing was flattened to approximately 1/16 inch and coiled with the 1/16 inch dimension parallel to the coil axis.

(d) A pyrex glass plenum chamber may be designed and used in place of plastic bag.

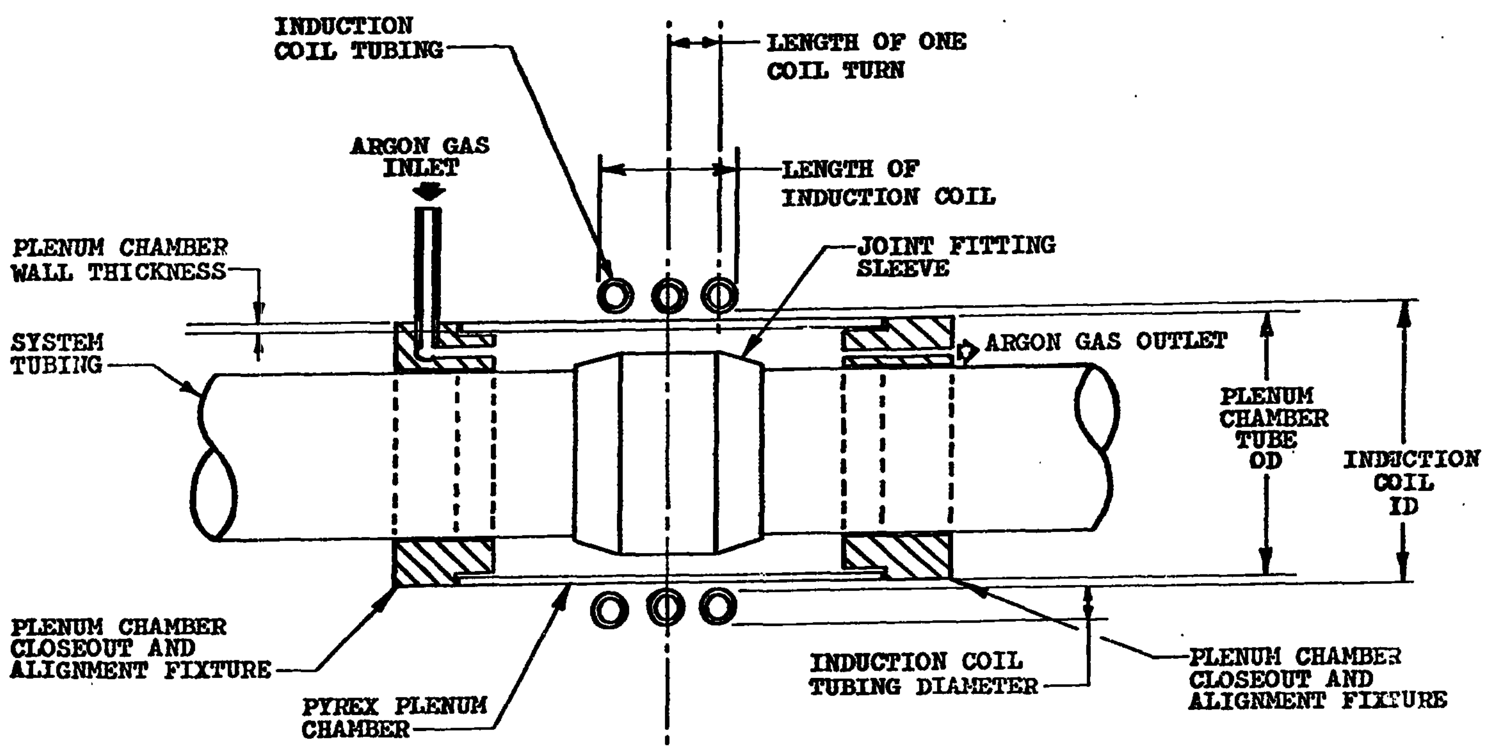
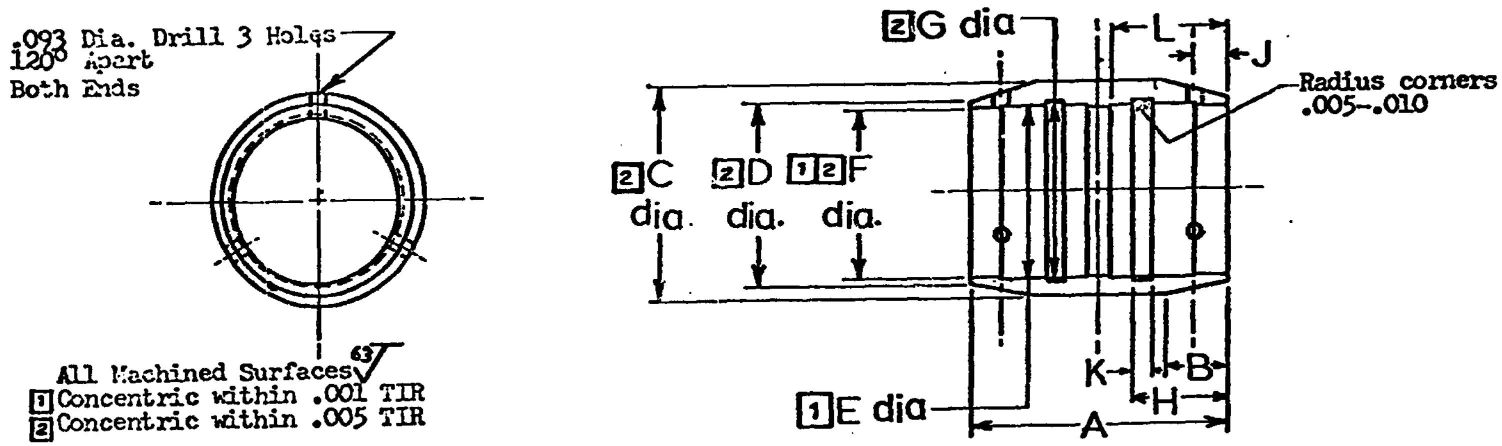


Figure 2. Schematic of Braze Tube Joining Induction Coil and Plenum Chamber Tooling Set-Up.



SLEEVE MATERIAL	TUBE OD	SLEEVE DIMENSIONS										
		A	B	C	D	E	F	G	H	J	K	L
AISI Type 347 Stainless Steel	1	1.500 ±.005	0.375 ±.010	1.255 ±.005	1.082 +.005 −.000	1.002 +.001 −.000	1.0005 +.001 −.000	1.055 +.005 −.000	0.550 ±.005	0.195 ±.005	0.100 +.005 −.000	0.6875 +.005 −.000
	3	3.335 ±.005	0.875 ±.010	3.720 +.010 −.000	3.130 ±.010	3.003 +.001 −.000	3.001 +.001 −.000	3.200 +.005 −.000	1.200 ±.005	0.245 ±.005	0.205 +.005 −.000	1.550 ±.005
AM 355 SCT Stainless Steel	1/4	0.559 ±.005	0.156 ±.010	0.400 +.005 −.000	0.321 +.005 −.000	0.254 +.001 −.000	0.251 +.001 −.000	0.276 +.005 −.000	0.223 ±.005	0.100 ±.005	0.040 +.005 −.000	0.245 +.005 −.000
	1	1.500 ±.005	0.375 ±.010	1.304 +.005 −.000	1.082 +.005 −.000	1.007 +.001 −.000	1.004 +.001 −.000	1.055 +.005 −.000	0.550 ±.005	0.195 ±.005	0.100 +.005 −.000	0.6875 +.005 −.000
Rene' 41	1/8	0.500 ±.010	0.125 ±.010	0.187 ±.005	0.158 +.005 −.000	0.128 +.001 −.000	0.128 +.001 −.000	—	—	—	—	—

TABLE II. DIMENSIONS OF FITTING SLEEVES.

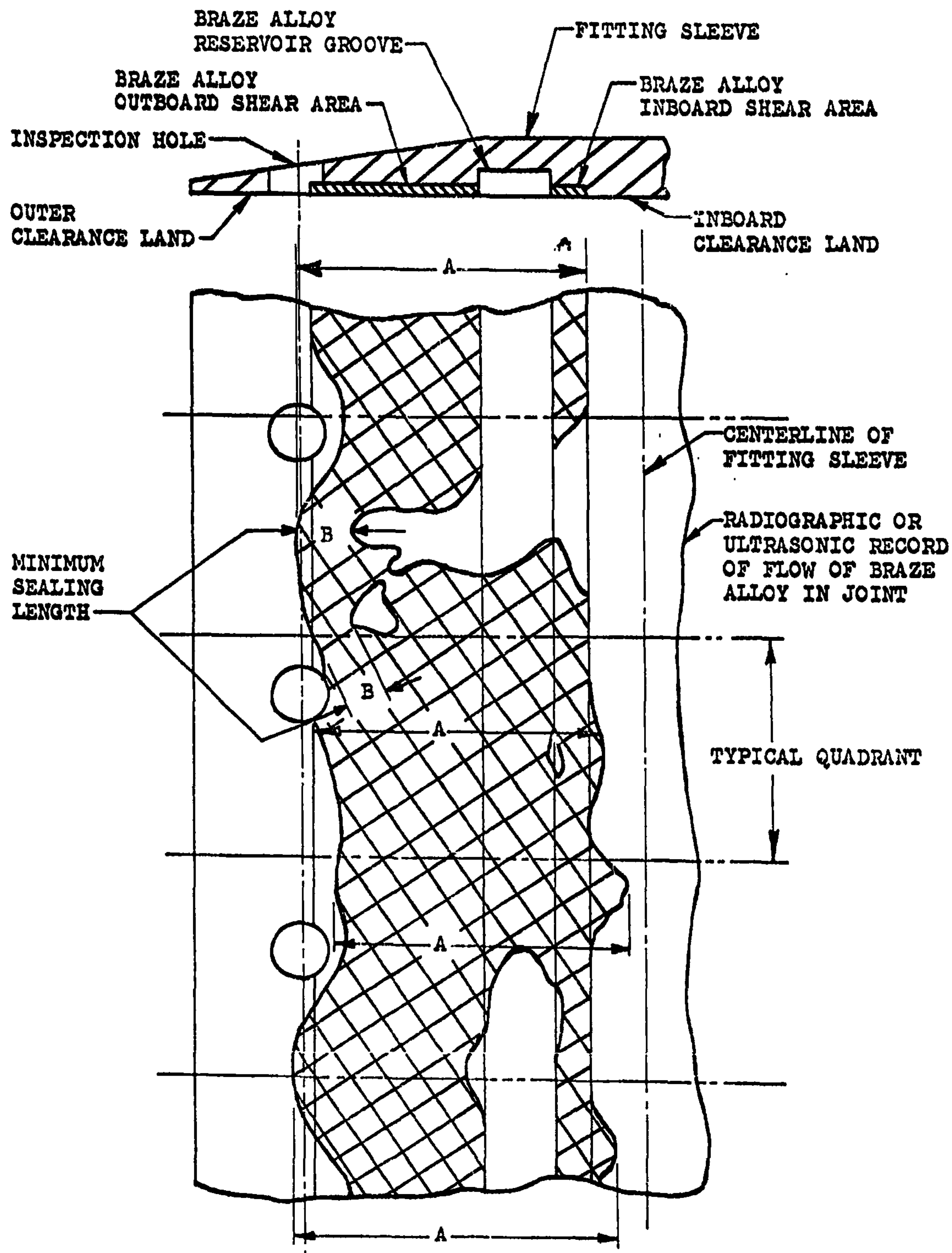


Figure 3. Relationship of Fitting Sleeve Design and Braze Alloy Flow.

TABLE III. CLEARANCE REQUIREMENTS OF BRAZED JOINT COMPONENTS.

NOMINAL DIAMETER OF TUBING IN INCHES	DIAMETRICAL CLEARANCE IN INCHES BETWEEN OD OF TUBING AND ID OF CAPILLARY CLEARANCE LAND OF FITTING SLEEVE		
	AISI 347 Tubing AISI 347 Fitting	AM 350 Tubing (a) AM 355 Fitting (b)	Rene' 41 Tubing Rene' 41 Fitting
1/8 to 5/16	0.002 to 0.003	0.000 to 0.001	0.003 to 0.004
3/8	0.002 to 0.003	0.000 to 0.0015	0.003 to 0.004
7/16 to 1/2	0.002 to 0.003	0.000 to 0.002	0.003 to 0.004
9/16 to 5/8	0.002 to 0.003	0.000 to 0.003	0.003 to 0.004
11/16 to 3/4	0.002 to 0.003	0.000 to 0.004	0.003 to 0.004
13/16	0.002 to 0.003	0.000 to 0.005	0.003 to 0.004
7/8	0.002 to 0.003	0.001 to 0.006	0.004 to 0.005
15/16	0.002 to 0.003	0.001 to 0.007	0.004 to 0.005
1	0.002 to 0.003	0.002 to 0.009	0.004 to 0.005
1-1/4	0.003 to 0.004	0.004 to 0.010	0.005 to 0.006
1-1/2	0.003 to 0.004	0.005 to 0.012	0.005 to 0.006
1-3/4 to 2	0.004 to 0.005	0.007 to 0.014	0.006 to 0.008
2-1/2	0.006 to 0.008	(c)	0.006 to 0.008
3	0.006 to 0.009	(c)	0.008 to 0.010

NOTES: (a) Heat Treat Condition SCT or CRT.
(b) Heat Treat Condition Solution Treated and Aged to Maximum Strength.
(c) AM 350 tubing not made in sizes large then 2 inch OD.

TABLE IV. HEAT TREATMENT CONDITION OF MATERIALS TO BE BRAZED PRIOR TO BRAZING.

COMPONENT OF JOINT	COMPONENT MATERIAL	HEAT TREATMENT CONDITION OF COMPONENT MATERIAL PRIOR TO BRAZING
Tubing	AISI 347 Stainless Steel	Annealed
Fitting Sleeve	AISI 347 Stainless Steel	Annealed
Tubing	AM 350 Stainless Steel	Condition SCT or CRT
Fitting	AM 355 Stainless Steel	Solution Treated and Aged to Maximum strength
Tubing	Rene' 41	Solution Treated and Aged
Fitting	Rene' 41	Solution Treated and Aged

described in paragraphs 4.3 and 4.4 are more severe and may be used where hot alkaline cleaning alone is not adequate to produce surfaces sufficiently clean to ensure proper flow of the braze alloy and quality of the joint. The tank electrolytic cleaning procedure is preferred over the brush electrolytic cleaning procedure. Brush electrolytic cleaning should be used only when tank electrolytic cleaning is not feasible, as when preparing part which are already assembled for further "in-place" brazing.

4.2 <u>Hot Alkaline Cleaning</u>

4.2.1 Alkaline clean by immersion in a bath consisting of 8 $\pm$ 2 oz. per gallon of Turco Products Vitro-Kleen with Turco No. 4215 additive. Immersion time shall be 15 to 20 minutes. The bath temperature shall be maintained at a temperature of 170 F to 200 F.

4.2.2 Rinse in demineralized water.

4.2.3 Pickle in inhibited nitric acid (7 to 9 percent HNO_3 plus 6 to 8 percent Turco 4104) at room temperature for 10 minutes.

4.2.4 Remove parts from the inhibited acid pickle and thoroughly flush the cleaned areas, including interior surfaces, in running demineralized water.

4.2.5 Dry parts by blowing with dry nitrogen or clean dry air.

4.3 <u>Tank Electrolytic Cleaning</u>

4.3.1 Alkaline clean per paragraph 4.2.1.

4.3.2 Rinse in demineralized water.

4.3.3 Rack parts so that areas to be brazed are well immersed in the electrolytic acid cleaning solution. The acid cleaning solution consists of 50 percent by volume of 85 percent phosphoric acid plus 5 percent by volume of Hamp-Ol 120 (Hampshire Chemical Corporation, Nashua, N. H.), and is operated at room temperature.

4.3.4 Clean tubing anodically (tubing positive) for 1-1/2 to 2 minutes at a current density of approximately 200 to 250 amperes per square foot of part surface, and clean fittings anodically for 45 to 60 seconds at the same current density. Reverse current and cathodically clean both tubing and fittings for 25 to 30 seconds.

4.3.5 Remove parts from electrolytic cleaning solution and thoroughly flush the cleaned area, including interior surfaces, in running demineralized water.

4.3.6 Dry parts by blowing with dry nitrogen or clean dry air.

4.4 Brush Electrolytic Cleaning

4.4.1 Plug ends of tubes with a plug which will prevent the cleaning solutions from running into the interior of the tubes. The plugs shall be designed in such a way that the tubes cannot possibly be assembled without removing the plug.

4.4.2 Hot alkaline clean per paragraph 4.2, if feasible. (Hot alkaline cleaning of tubing "in-place" cannot be performed.)

4.4.3 Wipe tube ends with fresh clean solvent (Methyl Ethyl Keytone, specification MIL-M-13999).

4.4.4 Anodically clean (part positive) outside diameter of tubing for a distance of two inches from each end using Dalic Cleaner No. 1 (Piddington and Associates, 3219 East Foothill Blvd., Pasadena, California) until a uniform bright surface is obtained. The anodic cleaning time should not exceed approximately two minutes per tube end. Any dc power source with output voltage between 6 and 12 volts may be used. The stylus design used for brush electrolytic cleaning is shown in Figure 4.

4.4.5 Rinse cleaned area with demineralized or distilled water.

4.4.6 Dry by blowing with dry nitrogen or clean dry air.

4.4.7 Remove plugs which were installed in tube ends.

4.4.8 CAUTION: When brush electrolytic cleaning is done "in-place", precautions must be taken to prevent spilling solutions into tubing or on adjacent structure. In case of accidental spillage, immediately rinse area thoroughly with water and then dry.

4.5 Cleaning of Brazing Alloy

4.5.1 Alkaline clean per paragraph 4.2.1.

4.5.2 Rinse in demineralized water.

4.5.3 Immerse in a solution of 3 to 7 percent by volume HNO_3 for four to six minutes.

4.5.4 Rinse in running demineralized water.

4.5.5 Wipe dry with clean, lint free cloths.

4.6 After the components to be brazed have been cleaned, they shall be protected from contamination until they are ready to be brazed. If brazing is not done within 24 hours after cleaning, the brazing alloy must be recleaned prior to assembly.

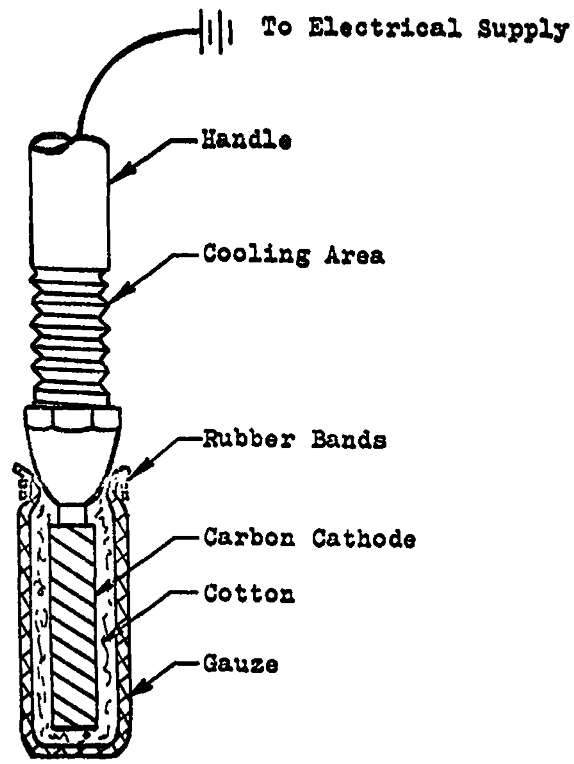


Figure 4. Design of Stylus for Brush Electrolytic Cleaning.

4.7 Glass Bead Peening

4.7.1 Glass bead peening may be used on stainless steel tubing and fittings to improve surface cleanliness and also induce residual compressive stresses in the surface material of the components which will improve their resistance to fatigue. When peening is required, the following procedure shall be used.

4.7.2 The surfaces of the components shall be glass bead peened in accordance with the requirements of specification AMS 2430 to an Almen Intensity of approximately 8A, using only clean glass beads which have been used previously only on stainless steels.

4.7.3 Following glass bead peening, the components shall be immersed in hot liquid Trichloroethylene for 2 to 5 minutes, hot air dried, and then Electrolytically Cleaned per paragraph 4.3 or 4.4.

5. HANDLING OF CLEANED PARTS

5.1 Particular care must be taken to prevent any tubing lines, especially those to be brazed in place, and other components, after they have been prebraze cleaned, from becoming contaminated by fumes, vapors, or dust generated by fabrication operations. Caution must be observed so that contamination from handling (perspiration, skin oils, etc.) does not occur.

5.2 If there is any question as to cleanliness of any parts to be brazed, the parts in question should be recleaned.

5.3 All components to be brazed (tubing, fittings, braze alloy) shall be handled with clean, white, lint free gloves or with clean tongs at all times during and after final cleaning.

5.4 After the components have been cleaned by the required procedure they shall be suitably protected from contamination until they are to be assembled for brazing.

5.5 Immediately prior to assembly for brazing the cleaned components shall be given a final wipe with Methyl Ethyl Ketone solvent. Other solvents may be used provided the braze joint quality requirements of paragraph 10 are met.

CAUTION: Do not allow the solvent used for the final prebraze assembly wipe to become contaminated by reuse or other means.

6. ASSEMBLY OF PARTS FOR BRAZING

6.1 Parts which have been cut, machined, or formed in any manner after having been through the prebraze cleaning aoperations of paragraph 4 shall be recleaned before being assembled for brazing.

CAUTION: IT IS EXTREMELY IMPORTANT TO PREVENT ANY FOREIGN MATERIAL, SUCH AS DIRT AND METAL PARTICLES, FROM ENTERING THE INSIDE OF THE TUBING OR FITTINGS PRIOR TO AND DURING ASSEMBLY FOR BRAZING, AND TO ENSURE THAT ANY SUCH PARTICLES WHICH MIGHT HAVE BEEN PRESENT PRIOR TO ASSEMBLY ARE REMOVED.

6.2 Preplacement of Brazing Alloy

6.2.1 Brazing alloy shall be used in the form of preform rings unless otherwise specified on the applicable detail component or joint assembly drawing. The brazing alloy material and the preform ring dimensions and fitting or sleeve dimensions shall be as specified on the applicable drawing. Dimensions of typical braze alloy preform rings for use with the tubing materials covered by this specification, and with the fitting sleeves of Table II, are shown in Table V.

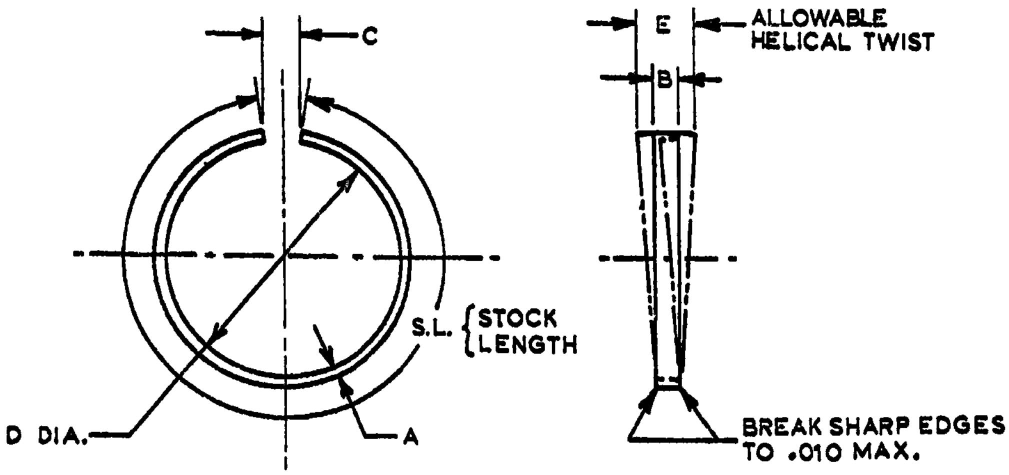
6.2.2 The braze alloy preform rings are assembled in the joint either by insertion into internal machined recesses or grooves in the fitting sleeve for tubing size 1/4 inch OD and large, or the braze alloy rings can be assembled between the butting ends of the tubes inside a smooth through-bored fitting sleeve for tubing sizes 3/16 inch OD and smaller, as shown in Figure 5.

6.2.3 Preplacement of the braze alloy preform rings is accomplished by compressing the ring enough to permit it to be inserted into the sleeve and positioned in the reservoir groove (for the larger size fittings) or in the center of the fitting bore length for the smooth bore fittings. Care should be exercised when compressing the ring to prevent any permanent deformation of the ring which would prevent it from fitting properly inside the fitting sleeve and thereby blocking insertion of the tubing.

7. ASSEMBLY OF JOINT FOR BRAZING

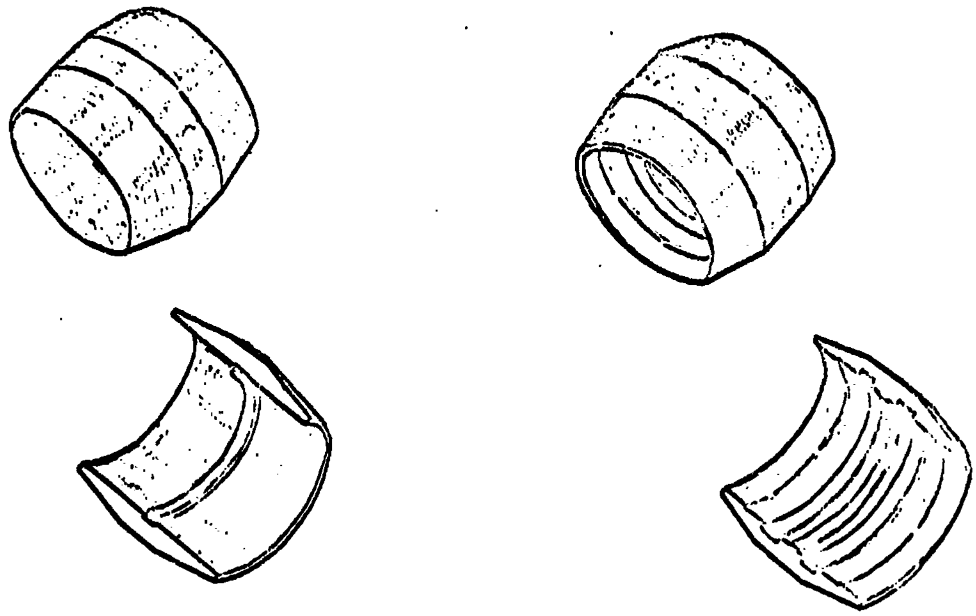
7.1 After preplacement of the braze alloy rings inside the fitting sleeve, the fitting is slipped onto one of the tube ends. The tubes are then aligned so that the tube ends, which were machined square within 1/2 degree, are positioned together with no greater than 1/32 inch gap between them, as shown in Figure 5. The fitting is then centered within ± 1/64 inch over the butting tube ends.

7.2 If the assembled joint is to be brazed with the fitting sleeve in other than a horizontal position, a stop shall be used to prevent the sleeve from moving (floating) away from the proper position during the brazing operation. The positioning technique or device shall not cause detrimental effects to the brazing process, such as by (a) changing the heat distribution in the joint, (b) contaminating the surfaces of the parts, or (c) contaminating the braze atmosphere inside the plenum chamber.



NOMINAL TUBE OD	A ±.001	B +.000 -.005	C +1/8 -0	D (REF)	E	S.L. ±.010
SILVER-BASE BRAZING ALLOY PREFORMS						
1/8	0.012	0.120	1/16	0.146	0.160	0.390
1/4	0.012	0.046	1/16	0.300	0.092	0.821
1/2	0.025	0.046	1/8	0.568	0.092	0.606
3/4	0.025	0.075	1/8	0.818	0.150	2.395
1	0.025	0.097	1/8	1.068	0.194	3.171
2	0.025	0.209	1/8	2.064	0.418	6.325
3	0.100	0.200	1/8	3.064	0.522	9.410
GOLD-BASE BRAZING ALLOY PREFORMS						
1/8	0.025	0.120	1/16	0.146	0.160	0.390
1/4	0.025	0.062	1/16	0.300	0.125	0.821
1/2	0.025	0.062	1/8	0.568	0.125	1.606
3/4	0.025	0.062	1/8	0.818	0.125	2.395
1	0.025	0.062	1/8	1.068	0.125	3.171

TABLE V. DIMENSIONS OF BRAZING ALLOY PREFORM RINGS.



STRAIGHT-THROUGH BORE
FITTING SLEEVE

Single ring of braze alloy is preplaced inside fitting sleeve between tube ends.

GROOVED-BORE
FITTING SLEEVE

Two preform braze alloy rings are preplaced in reservoir grooves machined in bore of fitting sleeve.

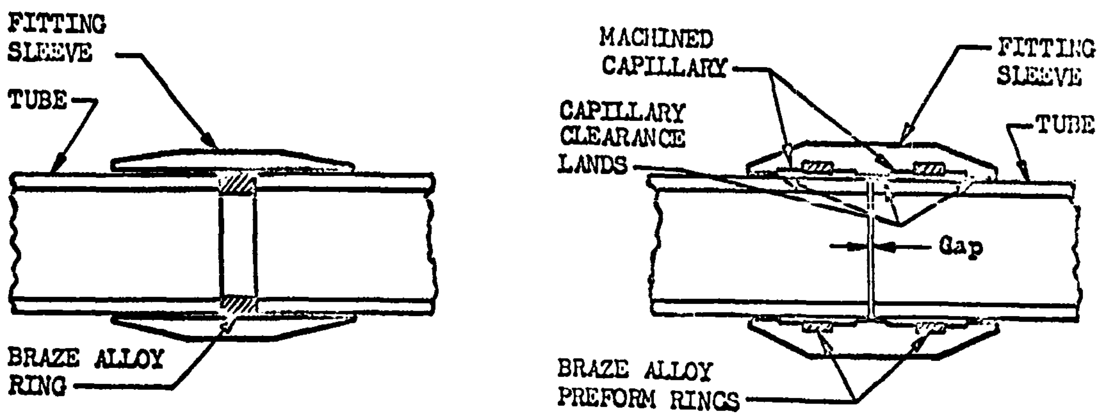


FIGURE 5. CONFIGURATIONS OF FITTING SLEEVES FOR BRAZE JOINING TUBING.

7.3 When it is necessary to prevent movement of the fitting sleeve from its assembled position, as specified in paragraphs 7.1 and 7.2, above, the sleeve may be secured to the tube by resistance tack welding one or more small strips of 0.005 inch thick stainless steel foil to the OD of both the sleeve and the tube.

8. ASSEMBLY OF BRAZE TOOLING

8.1 After the fitting sleeve has been positioned properly, as described in paragraph 7, the control thermocouple shall be attached to the OD of the tube. This thermocouple shall be located between 1/32 and 1/16 inch from the edge of the fitting sleeve. (See paragraph 9.2.1).

8.2 Assemble the inert gas enclosure or plenum chamber.

8.3 Assemble the induction coil around the joint. Unless a split induction coil is used, a throw-away type coil must be fabricated which is then discarded after the joint is brazed. The induction coil shall be positioned so that it is displaced from the center of the sleeve toward the purging gas inlet. The distance of displacement will vary and must be determined for the specific tool configuration and inert atmosphere gas flow rate. Approximately 1/32 inch displacement for small diameter tubes up to 1/2 inch OD, and larger displacements up to as much as 1/8 inch for three inch diameter tubes has been found sufficient to maintain even heating of the joint during the brazing operation.

8.4 After the tooling has been properly assembled and positioned, the control thermocouple is attached to the brazing temperature controller.

9. BRAZING

9.1 Purging

9.1.1 Dried argon gas shall be used to purge the plenum chamber surrounding the joint to be brazed and also the interior of the tubes being joined. The argon gas shall be dried to a moisture content of 10 parts per million or less of water.

9.1.2 During the brazing cycle the flow rate of the argon gas purge shall be maintained at a sufficient volume as to minimize oxidation of the tubing, the fitting sleeve, and the brazing alloy in order to ensure adequate flow of the brazing alloy. The actual flow rate of the purge gas will be dependent on the leakage of the gas through the tooling connections. Flow rates of 5 cubic feet per hour have been found to be satisfactory for brazing tube joints of 1/2 inch diameter and smaller, and a flow rate of 20 cubic feet per hour appeared to be adequate for brazing joints in tubes up to three inches in diameter.

9.1.3 The argon gas purge may be discontinued after the joint has cooled to a temperature below 500 F.

9.2 Braze Heating Cycle

9.2.1 Temperature Control

9.2.1.1 All braze heating cycles shall be temperature controlled. The approved method for controlling braze cycle temperatures is by use of thermocouples. Other temperature control methods, such as infrared detecting instruments, may be approved provided it can be demonstrated to Engineering that they will consistently provide the heat cycle control necessary to produce braze joints of acceptable quality.

9.2.1.2 When control thermocouples are used to control the braze heating cycle, the control thermocouple should be placed 1/32 inch to 1/16 inch from the edge of the fitting sleeve.

9.2.1.3 Control temperatures must be determined for each type and size of tube joint and for each tubing material in order to be sure that the brazing temperatures specified in paragraph 9.2.2 can be maintained. These control temperatures are determined during certification of the brazing tooling on a test joint which is identical to the production joints. In order to do this, thermocouples are placed on the inside diameter of the tubing at approximately the location of the brazing alloy reservoir groove, and the control thermocouple is placed in approximately the same position the control thermocouples will be placed on the production joints. The test joint is then heated to the minimum and maximum temperatures specified in paragraph 9.2.2 as registered on the thermocouples on the inside surface of the tubing, and the induction machine settings and the control thermocouple temperatures recorded at each of these temperatures.

9.2.2 Braze Heating Cycle Temperature

9.2.2.1 The brazing temperature to which the joint is heated should be sufficiently high that the braze alloy will flow throughout the entire braze capillary area, but not so high that the braze alloy becomes too fluid and flows out of the joint or that the strength and other properties of the tubing outside the joint area are adversely affected.

9.2.2.2 The rate of heating must be controlled to prevent overheating the tubing outside the joint area, burning or localized overheating of the fitting sleeve, and to prevent overshooting of the control temperatures. Time cycles of one to two minutes for heating to brazing temperature are recommended for joints up to about two inches in diameter, and somewhat longer cycles for joints in larger diameter tubing.

9.2.2.3 The temperatures at the braze joint area and at the control thermocouple location are determined by the melting and flow temperatures of the brazing alloy used and also by the heat treatment temperatures of the tubing and fitting sleeve materials. Recommended joint temperatures and suggested control thermocouple temperatures are given in Table VI for several tube materials and brazing alloys which may be used in rocket propulsion fluid systems.

TABLE VI. RECOMMENDED TEMPERATURES FOR BRAZING TUBING JOINTS.

MATERIALS OF BRAZED JOINT			RECOMMENDED TEMPERATURES AT BRAZE ALLOY RESERVOIR		SUGGESTED TEMPERATURES FOR CONTROL THERMOCOUPLES LOCATED FROM SLEEVE EDGE	
TUBING	FITTING	BRAZE ALLOY	MINIMUM	MAXIMUM	1/16 INCH	1/32 INCH
AISI 347 Stainless Steel	AISI 347 Stainless Steel	71.8Ag-28Cu-0.2Li	1450 F	1500 F	1050 F	1500 F
AM 350 Stainless Steel Cond SCT or CRT	AM 355 Stainless Steel Cond SCT	81.7Au-18Ni-0.3Li	1825 F	1875 F	1050 F	1500 F
Rene' 41 Alloy	Rene' 41 Alloy	70Au-22Ni-8Pd	1950 F	2000 F	1500 F	1900 F

10. BRAZE JOINT QUALITY REQUIREMENTS

10.1 Inspection Methods

10.1.1 Each joint shall be inspected by visual and radiographic or ultrasonic techniques. All joints shall be visually inspected for flow of braze alloy beyond the outside edge of the fitting sleeve. The brazed joints shall have concave fillets at the inboard edges of all inspection holes in the fitting, and shall show evidence of braze alloy wetting the tube at the inspection holes.

10.1.2 Where the braze alloy filleting and wetting provisions are met, but visual inspection indicates one or more voids of unknown size extending toward the center of the fitting from the inboard side of the inspection holes, acceptance of the joint shall be based on the results of the radiographic or ultrasonic inspection, as described below.

10.2 Voids

10.2.1 Voids in the braze alloy shear area shall not exceed 15 percent of the total design shear area.

10.2.2 The minimum sealing length, denoted by the dimension "B" in Figure 3, is the shortest distance between two adjacent voids or between a void an the nearest edge of braze alloy flow. The minimum sealing length of a joint shall be not less than the length given in the table below.

Nominal Tube Diameter (inches)	Minimum Sealing Length (inches)
1/4	0.018
3/8	0.023
1/2	0.029
5/8	0.038
3/4	0.051
1	0.070
1-1/4	0.105
1-1/2	0.138
1-3/4	0.167
2	0.198
2-1/2	0.270
3	0.350

10.3 Joint Fit-Up

10.3.1 Poor fit-up and joint slippage during brazing are not permitted.

10.3.2 After brazing, inspection must show that the tube is inserted through the inboard braze capillary and extends onto the inboard clearance land a minimum distance of 0.005 inch.

10.4 Certification

10.4.1 Adequate in-process quality controls must be maintained to ensure compliance with this specification. There are minimum tests which must be performed and records which must be kept to ensure acceptable quality brazed joints.

10.4.2 At the prerogative of Engineering tests shall be conducted on test samples of induction brazed joints produced during bench or in-place production assembly operations. The configuration of the test samples and the ratio of the number of test samples to production joints shall be in accordance with Engineering directives. The same tools, materials, techniques, and personnel shall be used to make the test samples as are used to braze the production joints.

10.4.2.1 The test samples shall be subjected to tensile proof tests conducted in accordance with the procedure of ASTM specification A370-62, Supplement II. The values of the tensile proof loads shall be determined from calculations based on the tubing wall thickness and material strength, and shall be at a level of 90 percent of the yield strength of the material of the tubes being joined.

10.4.2.2 After completion of the tensile proof tests, the undamaged joints shall be sectioned and peeled to determine the flow properties of the braze alloy.

10.4.3 The information listed below, including the results of the tensile proof tests and the peel inspection, shall be recorded for each brazed joint in case future reference to it is necessary.

(a) Identification of joint

(b) Braze alloy type and lot number

(c) Identification of tooling and equipment for brazing

(d) Induction generator power settings

(e) Purge gas flow rate

(f) Moisture content of purge gas

(g) Time of overall heating cycle

(h) Time at braze temperature

(i) Maximum temperature reached during brazing cycle

(j) Operator's name and identification

(k) Inspectors name and identification

(l) Inspector's report of visual inspection and comments

(m) Date joint brazed

(n) Results of radiographic and/or ultrasonic inspection

11. REPAIR AND REBRAZING OF JOINTS

11.1 Repair. After a joint has been brazed and inspected and has been found to fail to meet the requirements of this specification, the joint may be reheated twice through the temperature cycle of paragraph 9.2.2 to correct one or more of the defects listed below.

11.1.1 Correctable Defect Repaired by Reheating Only

11.1.1.1 Minimum sealing length too short due to poor distribution of braze alloy.

11.1.1.2 Braze shear area voids total greater than 15 percent of total braze shear area.

11.1.2 Correctable Defect Repaired by Reheating and Repositioning Tube

11.1.2.1 Tube inserted through the inboard braze capillary but extending onto the inboard clearance land less than 0.005 inch.

11.1.3 Limitations on Repair by Reheating of Brazed Joints

11.1.3.1 The maximum temperatures specified in paragraph 9.2.2 must not have been exceeded on previous heating cycles.

11.1.3.2 The total heating time between the minimum and maximum temperatures listed in paragraph 9.2.2 must not have exceeded 210 seconds, including the third heating (second reheating).

11.1.3.3 No evidence has been observed of braze alloy from previous heatings flowing beyond the outside edge of the fitting sleeve.

11.1.3.4 The braze alloy remaining in the reservoir groove must be sufficient to fill the void and maintain the alloy seal.

11.1.3.5 The previous heating resulted in a reduction of the defect.

11.2 Rebrazing

11.2.1 Debrazing of the fitting sleeve and rebrazing of the joint may be done only with the approval of Engineering.

11.2.2 The joint to be debrazed shall be enclosed in a chamber which will permit effective external and internal argon gas purging of the joint.

11.2.3 The debrazing chamber shall be of such size as to permit the debrazed tube to be drawn clear of the fitting without exposing the heated portion of the tube to an oxidizing atmosphere. An extra-long plenum chamber is, therefore, recommended for the debrazing operation.

11.2.4 The induction heating coil shall closely fit the outside diameter of the argon gas enclosure, and shall contain the same number of turns as the coil on the certified tool which was used to braze the joint originally, and shall be positioned so that the tubing to be reused will not be subjected to excessive temperature during the debrazing cycle.

11.2.5 The time of heating and the power required to debraze a joint shall not exceed the heating time and power used to braze the joint originally. The requirement of paragraph 11.1.3.2 concerning total time a temperature shall also apply.

11.2.6 All debrazing operations shall be witnessed by an Inspector.

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